Europe's ecological backbone: recognising the true value of our mountains

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Executive summary

Introduction and background

Europe's mountain areas have social, economic and environmental capital of significance for the entire continent. This importance has been recognised since the late 19th century through national legislation; since the 1970s through regional structures for cooperation; and since the 1990s through regional legal instruments for the Alps and Carpathians. The European Union (EU) first recognised the specific characteristics of mountain areas in 1975 through the designation of Less Favoured Areas (LFAs). During the last decade, EU cohesion policy and the Treaty of Lisbon have both focused specifically on mountains.

A wide range of policies, from numerous sectors and levels of governance, influence the management of Europe's mountains. The key EU policy domains address agriculture and rural development, forestry, regional and cohesion policy, and nature conservation and biodiversity, although numerous other relevant and interacting policy domains exist. Some European countries have enacted specific legislation areas addressing their mountainous regions; others address them through sectoral or multisectoral approaches. There are also two regional agreements for the Alps and the Carpathians. Given the range and complexity of these various policies, there is a need to understand their interactions in order to formulate effective policy responses to contribute to sustainable development.

Europe's mountains have been delineated in various ways, for example:

- for the purposes of national and EU policies, particularly regarding agriculture and, more recently, territorial cohesion;
- for the purposes of regional conventions;
- for the purposes of studies commissioned by the European Commission in 2004 and the present EEA report.

The present report delineates Europe's mountain areas according to topography and altitude criteria, based on data from digital elevation models. For the purposes of this study, 36 % of Europe's area is defined as mountainous, including 29 % of the EU-27. Massifs also served as a unit of analysis and 15 were defined.

This report is based on a highly variable evidence base. For certain variables, comprehensive datasets are only available for EU Member States. Comprehensive Europe-wide datasets are only available for a few variable and topics, often only for one point in time. To help overcome these data gaps, many issues are illustrated through regional, national or sub-national case studies.

Mountain people: status and trends

Mountain areas often have low population densities because much of their area is unsuitable for human habitation. Densities in valleys may, however, be as high as in lowland areas. In total, 118 million people live in Europe's mountains (17 % of Europe's population), including 33 million in Turkey. In the EU, 63 million people (13 % of the population) live in mountain areas.

Ten European countries have at least half of their population living in mountains: Andorra, Liechtenstein, Monte Carlo, Switzerland, the Faroes, San Marino, the former Yugoslav Republic of Macedonia, Bosnia and Herzegovina, Slovenia and Austria. The highest population densities are found in very small states: Andorra, Liechtenstein, Monte Carlo, and San Marino. Except for such small countries, population densities in the mountain parts of countries are always less than outside the mountains.

Economic and political changes have influenced mountain populations significantly. From 1990 to 2005, population density across Europe's mountains as a whole increased considerably, although at the level of both massifs and countries, there were both increases and decreases. The differences cannot easily be clustered in north-south, west-east or other terms, such as formerly socialist or not. In general, population trends in mountain areas were similar to those in the country as a whole. In Poland, Serbia, Slovenia and Switzerland, however, relative population increases were higher in mountain areas. In Finland, Italy, Portugal and Sweden, they were lower there.

Mountain economies and accessibility

The economic structures in Europe's mountains vary greatly and many have changed rapidly in recent years, especially in new EU Member States. While the primary (natural resource) sector remains important for cultural identity and as a source of employment, especially in southern and eastern Europe, the tertiary (service) sector is the greatest source of employment in the mountains of all EU Member States except the Czech Republic and Romania, as well as in Norway and Switzerland.

There is high heterogeneity in economic density within and between massifs, deriving both from internal national differences and the proximity of major urban centres. Generally, mountain areas are less accessible than non-mountain areas but there is great variability within both massifs and countries. One EU initiative to decrease such disparities is the Trans-European Transport Network (TEN-T). The massifs whose populations are most influenced are in the more densely populated parts of Europe: the Alps, Pyrenees, French/Swiss middle mountains; and Iberian mountains.

Ecosystem services from Europe's mountains

Europe's mountains provide a wide range of ecosystem services, although these vary greatly at all spatial scales. Provisioning services come from agricultural and forestry systems; natural ecosystems; and rivers, which provide water and hydroelectricity. Regulating services relate particularly to climate, air quality, water flow, and the minimisation of natural hazards. Cultural services are associated with tourism, recreation, aesthetics, protected areas and locations of religious importance. Services of increasing importance relate particularly to water regulation, protection against natural hazards, tourism, recreation, and forests. It is important to recognise that mountain ecosystems are highly multifunctional. Because the benefits of services accrue to both mountain and lowland populations, maximising highland-lowland complementarities is important to all. However, trade-offs may often have to be made.

Climate change and Europe's mountains

The climate of Europe's mountains has changed over the past century, with temperatures and snowlines both rising. Changes in precipitation have varied regionally. The availability of climatic data varies greatly between regions, with the longest records and most dense recording networks in the Alps, followed by the Carpathians and the mountains of the British Isles and Scandinavia. The availability of such data, as well as the technical challenges of using climate models — especially for regions with complex topography — mean that predicting future climates is uncertain.

It is likely that temperatures will continue to increase, especially at higher altitudes, and that summer precipitation and wind speeds will increase in northern Europe and decrease in southern Europe. In the Alps and Pyrenees, snow fall and snow cover increased during the last century and these trends are predicted to continue. The lower elevation of permafrost is likely to rise by several hundred metres. All these changes will significantly affect diverse ecosystem services and economies across Europe.

The water towers of Europe

Europe's mountains are 'water towers', providing disproportionate amounts of runoff in comparison to lowland areas and, hence, diverse ecosystem services at all spatial scales. Changes in land use, hydropower development, and climate change may all affect the provision of these services.

Mountains are major sources of hydropower. Most potential sites in the Alps, and many in other massifs, have been developed. The associated reservoirs and dams affect both hydrological and ecological systems. Water quality has improved in mountain lakes, rivers and streams following the implementation of policies to decrease water and air pollution from diverse sources.

Floods, often originating in mountain areas, are the most common natural disaster in Europe, leading to widespread impacts. The number of reported flood events has risen for various reasons, including better reporting, and changes in land-use and climate. Most of the damage is caused by a few severe events. Better flood protection requires not only structural changes along river systems but also better monitoring, prediction, coordination and information exchange.

The temperature of mountain lakes, rivers and streams has increased in recent decades. This trend, together with receding glaciers, seasonal changes in runoff and more frequent and severe floods, will lead to significant changes in water availability, with impacts on both human and natural systems. Conflicts between sectors are likely to increase. All of these changes imply a greater need for more effective processes and policies to address uncertainty.

Land cover and uses

The land cover of Europe's mountains largely reflects complex interaction of cultural factors over very long timescales. Forests cover 41 % of the total mountain area — over half of the Carpathians, central European middle mountains, Balkans/South-east Europe, Alps, and Pyrenees — and are the dominant land cover except in the Nordic mountains. Three land-cover types each cover just under one sixth of Europe's total mountain area:

- pasture and mosaic farmland, especially in central and south-eastern Europe;
- natural grassland, heath and sclerophyllous vegetation, especially in the Nordic mountains, Turkey, and the Iberian mountains;
- largely unvegetated open space, especially in the Nordic mountains and Turkey. Arable land is most common in southern Europe.

From 1990 to 2006, the greatest changes in land cover were in the central European middle mountains, the Iberian mountains and the Pyrenees. Overall, the dominant change was forest creation and management. In new EU Member States, changes in types of farming were also important, especially from 1990 to 2000.

In total, 69 % of the mountain area of the EU-25 has been designated as Least Favoured Area under Article 18 (mountains) of the LFA regulation, although none in Hungary, Ireland or the United Kingdom. A further 23 % is designated under Articles 16, 19 and 20. High Nature Value (HNV) farmland covers 33 % of the total mountain area of the EU — almost double the proportion for the EU as a whole. LFA and HNV designations overlap considerably: only 5 % of the area designated as HNV is not designated under LFA.

Biodiversity

Most European biodiversity hotspots are in mountain areas. Among the 1 148 species listed in Annexes II and IV of the Habitats Directive, 181 are exclusively or almost exclusively linked to mountains, 130 are mainly found in mountains and 38 occur in mountains but mainly outside them. These include 180 endemic species found only in one country, including 74 found only in Spain. Of the 214 mountain species restricted to a particular biogeographic region, 114 are endemic to the Mediterranean, 51 to the Macaronesian region and 42 to the Alpine region.

Of the 231 habitat types listed in Annex I to the Habitats Directive, 42 are exclusively or almost exclusively linked to mountains and 91 also occur in mountain areas. Almost half of these are forests. Only one habitat group — temperate heath and scrub — has most of its habitat types in mountains. The majority of natural grassland habitat types are also found in mountains. For mountain habitat types as a whole, 21 % are assessed as having a favourable status, 28 % an unfavourable-inadequate status, 32 % an unfavourable-bad status, and 18 %, mainly in Spain, as unknown. In most countries except for Ireland and the United Kingdom, the proportion of habitat types with a favourable status is higher in the mountains than outside them.

Mountain areas provide favourable habitats for many bird species but can also be significant barriers to migration. The Eurasian high-montane (alpine) biome is one of the five biome types containing species that are seldom found elsewhere. Based on the existing classification of habitats for birds and available data it is difficult to present information about the status of mountain birds and their habitats.

Climate change has already caused treelines to shift upwards and will affect biota both directly and indirectly. For plants and other species with restricted mobility, upslope migration is a limited option. Europe's mountain flora will therefore undergo major changes, with increased growing seasons, earlier phenology and upwards shifts of species distributions. Such changes will be influenced by inter-specific interactions and land uses. It is likely that many species will become extinct.

Protected areas

For centuries, specific parts of Europe's mountains have been protected to ensure continued provision of ecosystem services. Of the total area designated as Natura 2000 sites, 43 % is in mountain areas, compared to 29 % for the EU as a whole. These sites cover 14 % of the mountain area of the EU.

Among all Europe's massifs, the Iberian mountains have the greatest proportion of their area in Natura 2000 sites. Nationally, Slovenia has the greatest proportion of its mountain area in these sites, followed by Slovakia, Spain and Bulgaria. In general, countries with a high proportion of their area in mountains have an even greater proportion of their Natura sites in mountains.

Between 1990 and 2000, artificial and agricultural land cover changed less in Natura 2000 sites than outside them. This was generally also true for forests. In the EU as a whole, Natura 2000 sites cover a smaller proportion of mountain land than HNV farmland, although the relative proportions vary considerably across massifs and countries.

In total 15 % of Europe's total mountain area lies within sites that countries have designated for conservation (nationally designated areas, NDAs). The highest proportions are in the small massifs of central Europe. Among larger massifs, proportions are particularly high in the Alps and the Nordic mountains. In most EU Member States, the proportion of mountain land within NDAs is higher than that within Natura 2000 sites. The extent to which these national and EU designations overlap varies considerably.

Integrated approaches to understanding mountain regions

Three typologies are presented to provide greater understanding of interactions between human populations and their environments. Most of Europe's mountain areas are 'deep rural', with low economic density and accessibility. In all countries with a significant mountain area, deep rural zones account for a greater proportion of the mountains than of other regions. However, some countries, especially Alpine countries, have high proportions of rural and even peri-urban areas in their mountains.

In EU Member States, mountains account for a greater proportion of a country's natural and environmental assets than non-mountainous areas. In terms of wilderness, the greatest proportion and area in Europe is found in the Nordic mountains. Elsewhere, only Spain has more than 10 000 km^2 of mountain wilderness.

1 Introduction and background

1.1 Introduction and objectives

Mountains are the 'undervalued ecological backbone of Europe' (EEA, 1999), providing essential ecosystem services and important marketed goods and services. They provide opportunities for Europe and have significant social, economic and environmental capital at the European scale. While the exploitation of the mineral deposits and forests of Europe's mountains has a centuries-old history, formal recognition of the importance of mountains as sources of ecosystem services began in the 19th century when individual states first gave specific status to their mountain areas in national laws. The first such laws in various Alpine countries underlined the need for protective forests to ensure reliable flows of water and minimise risks of floods (Farrell *et al.*, 2000). From the second decade of the 20th century, states also began to recognise the high biodiversity and landscape values of specific parts of their mountains through designation as national parks: from 1909 in Sweden; from the 1910s in Spain and Switzerland; the 1920s in Italy; and the 1930s in Bulgaria, Greece, Poland, and Romania (IUCN, 1992). Since the Second World War, these and other areas with attractive landscapes and opportunities for recreation have increasingly become focal points for tourism, and tourism is now one of the major economic sectors in the European mountains. Nevertheless, more traditional economic activities have continued, and the importance of maintaining economically-active populations in mountain areas has been increasingly recognised in national legislation, with particular attention being paid to support for agriculture and the provision of services and infrastructure. Such legislation dates from the 1920s in Switzerland (Rudaz, 2005). In Italy, mountains were identified in the 1946 Constitution as requiring specific statutory advantages (Castelein *et al.*, 2006), which led to targeted legislation from the 1950s. Comparable legislation also followed from the 1960s in Austria and France (European Commission, 2004b).

The Alpine countries were also the first to develop transnational approaches to mountain regions, with the foundation of the International Commission for the Protection of Alpine Regions in 1952. At a subregional scale, working communities were established for different parts of the Alps from 1972 to 1982, and subsequently in the Pyrenees in 1983 and the Jura in 1985 (Price, 1999). All of these initiatives recognised the reality that, while mountains often form frontiers between states, these frontiers often divide landscapes and ecosystems. However, people, other species, pollution, and water often cross these frontiers so that cooperation to address joint issues is essential. At a wider scale, the European Economic Commission published a Directive on mountain and hill-farming in less-favoured areas in 1975. This was the first European document to recognise that specific resources needed to be directed to agriculture in mountain areas, particularly because of physical constraints. A European perspective on mountain issues was also taken by the Council of Europe in 1978, when the European Conference of Ministers responsible for Regional Planning organised a seminar on 'Pressures and regional planning problems in mountain regions'.

The attention given to mountain areas increased significantly from the early 1990s, both in Europe and globally (Castelein *et al.*, 2006; Price, 1998). The Alpine Convention was signed by the Alpine states and the European Community, and the (European) Association of Elected Representatives from Mountain Areas (AEM) was established in 1991. In 1992, mountains achieved recognition in the global arena, with the inclusion of a specific chapter in 'Agenda 21', the plan of action endorsed at the UN Conference on Environment and Development in Rio de Janeiro. Chapter 13 of this document is entitled 'Managing Fragile Ecosystems: Sustainable Mountain Development' and it placed mountains in the context of sustainable development on an equal footing with climate change, tropical deforestation, desertification and similar issues (Price, 1998). At the global scale, mountains have been specifically considered in the UN Framework Convention on Climate Change, in a Programme of Work for Mountain Diversity under the Convention on Biological Diversity (2004), in the Millennium Ecosystem Assessment (Körner and Ohsawa, 2005), and through the designation of the year 2002 as the

International Year of Mountains. During this year, the World Summit on Sustainable Development adopted a Plan of Implementation in which paragraph 42 is specifically devoted to mountains. At the same meeting, the Mountain Partnership was created as a 'voluntary alliance of partners dedicated to improving the lives of mountain people and protecting mountain environments around the world' (www.mountainpartnership.org). European activities are coordinated through the Environmental Reference Centre at the Vienna Office of the United Nations Environment Programme (UNEP).

One outcome of Chapter 13 of 'Agenda 21' is a series of intergovernmental consultations on sustainable mountain development. The two European sessions took place in 1996 and involved 21 states and the European Commission (Backmeroff *et al.*, 1997). These meetings took place in a wider context, as exemplified by other meetings in the 1990s, including: the 3rd European conference on mountain regions, organised by the Council of Europe's European Congress of Local and Regional Authorities in 1994 (Council of Europe, 1995); the international conference on 'Europe's mountains: new cooperation for sustainable development', organised by Euromontana in 1995 (Euromontana, 1995) which led to its establishment as a legal association in 1996 and a consultation of non-governmental organisations (NGOs), including both a detailed questionnaire on sustainable mountain development and an international meeting with participants from 24 countries, in 1996 (Price, 2003), which led to the creation of the European Mountain Forum in 1998. All of these initiatives showed that mountains were of increasing importance to local, regional and national authorities, European institutions, and NGOs throughout the 1990s.

By the year 2000, mountains were a particular theme of regional policy within the European Commission (2001b), and the Second Report on Economic and Social Cohesion (European Commission, 2001b) specifically identified them as regions with 'permanent natural handicaps' in. In this context, the European Commission's Directorate-General for Regional Policy commissioned a report on the mountain areas of all current member states of the EU in which Norway and Switzerland were also included. The resulting document (European Commission, 2004b) was the first comprehensive overview of the mountains of these countries. However, it showed that detailed information relating specifically to mountain areas was unavailable for very many themes. A similar conclusion was drawn at the MONTESPON seminar in 2006 (Swiss Federal Office for Spatial Development, 2006). This situation limits possibilities to make informed statements about these areas and compare situations both within and between different countries. Nevertheless, in the context of territorial cohesion and relevant laws and policies, it is necessary to identify common issues, starting with land use and including social structure of mountain regions, that recognise the complex linkages between human presence and environmental characteristics, past and present.

Since 2004, there has been a considerable increase in the availability of European-level data which can be analysed to present an overview of the current situation in the continent's mountain areas. The objective of the present report is to provide a comprehensive integrated assessment of the current status of and trends relating to the environment and sustainable development of the mountains of Europe, in order to provide the information needed for the development and implementation of relevant policies. Within the limits of available data and information, this report aims to:

- be Europe-wide and based on quantitative data of as high a spatial resolution as possible. It builds particularly on the EEA Land and Ecosystem Accounts (LEAC) framework for the assessment of land-use changes and associated environmental concerns (Haines-Young and Weber, 2006) which are complemented by qualitative data and case studies where data are lacking at the European scale to illustrate specific issues;
- be as integrated as possible in that it not only considers changes with regard to specific issues but also the relationships between them;
- be based around the principle of environmental sustainability, which requires an integrated ecosystem-based approach relating to narratives of what affects what (interactions) in order to understand what policies are or are not working, where and why;
- consider relationships and independencies between mountain areas and their resources and the wider European context; not only by analysis of states, trends and interactions within the mountains, but also their wider linkages and implications both between different mountain areas (e.g. connectivity) and between mountain areas and lowlands; and
- provide results at a spatial scale that is meaningful and relevant for the development and implementation of policies at appropriate levels.

1.2 The legislative and policy framework for Europe's mountain areas

The key public policy challenge facing mountain areas lies in safeguarding their environment as the 'ecological backbone of Europe' (EEA, 1999), whilst also enhancing their economic competitiveness and social cohesion; the essence of sustainable development. Inevitably, this is a complex process, given the diverse, multi-level and multi-faceted public policy environment in which Europe's mountain areas are located. The aim of this section is to provide an overview of this policy environment by examining relevant policy frameworks at different scales of governance and highlighting key debates that shape the continuing evolution of public policy as it relates to Europe's mountain areas.

1.2.1 European mountain policies in context

There is no single, sectorally and territorially integrated policy framework for Europe's mountains. Instead, policy processes unfold at various scales of governance from the top down and from the bottom up. Thus, globally, mountain areas are the subject of a specific chapter in 'Agenda 21' and subject to the protocols of a variety of international conventions with an environmental or conservation focus; for example, the UN Convention on Biological Diversity.

At the pan-European level, a draft European convention on mountain regions was discussed and developed by various structures within the Council of Europe during the 1990s. However, in 2000, while the Congress of Local and Regional Authorities (CLRAE) adopted a recommendation supporting this document, the Committee of Ministers decided not to approve it. Thus, the only formally approved pan-European document that specifically addresses integrated approaches for mountain regions is resolution 136 of the CLRAE in 2002 on 'A new political project for Europe's mountains: turning disinherited mountain areas into a resource' (Déjeant-Pons, 2004). With specific regard to mountain forests, in 1990, the Ministerial Conference on the Protection of Forests in Europe adopted Resolution S4 on 'Adapting the management of mountain forests to new environmental conditions' which has led to the publication of two overview documents (Buttoud *et al.*, 2000, Zingari and Doro, 2006).

As mountain areas comprise a significant proportion of Europe's area, and include both rural and urban areas, almost all legal instruments deriving from the Council of Europe and European Ministerial Conferences apply in one way or another to mountain areas. This is also true at the spatial scales of the European Union (EU), individual states, and sub-national entities such as provinces and regions. Nevertheless, certain legal instruments do apply specifically to mountain areas, or are particularly relevant to them; and it is these instruments that are the focus of this section. Such instruments are also addressed in Chapter 8 of the European Commission (2004b) report, Castelein *et al.* (2006), Treves *et al.* (2002, and the website of the Policy and Law Initiative of the Mountain Partnership (Mountain Partnership, 2008).

At the EU level, measures relating to agriculture, rural and regional development and nature conservation are important in shaping policy interventions within Member States although comparatively few of these are specifically targeted at mountain areas. However, it should be noted that the conclusions of the informal Ministerial meeting on 'The Specificity of Mountain Areas in the European Union', in Taormina, Italy on 14–15 November 2003 stated that the specificity of mountain areas should be, in principle, recognised in the EU, as well as in the framework of existing agreements on cooperation in European mountain areas. This was taken further in the Treaty of Lisbon in which Article 131 modifies Article 158 of the Treaty on European Union (now article 174 of the consolidated version of the Treaty on the Functioning of the European Union: EU, 2008), stating that 'particular attention shall be paid to rural areas, areas affected by industrial transition, and regions which suffer from severe and permanent natural or demographic handicaps such as the northernmost regions with very low population density and island, cross-border and mountain regions.'

Within Member States themselves, distinctive policy approaches have evolved over time reflecting specific priorities and preferences as regards the development and implementation of policies impacting upon their mountain areas. As Dax (2008) notes:

[T]he majority of European countries dispose of mountain policies only implicitly: in general, these are mainly sectoral policies with specific adaptations. From the perspective of many public and private actors, they are also often essentially overlapping with rural or regional policies.

The European Commission (EC, 2004b) study of mountain areas in Europe arrived at broadly the same conclusion. It identified four different types of countries in relation to their approach to mountain policies:

- countries where no mountain policies can be identified due to the absence of mountains. These include Denmark, Estonia, Latvia, Lithuania, Malta and the Netherlands;
- countries where mountain policies/measures are sectoral and in which agriculture is the dominant sector. These include Ireland, Hungary, Portugal and Slovakia;
- countries where mountain policies are addressed to multi-sectoral development including agriculture, public infrastructure/services, training, regional development and environment. These include Germany, Spain and Austria;
- countries where mountain policies are addressed to overall development through the consolidation of sectoral policies and the passing of specific mountain legislation and provision of specific mountain funds. These include France and Italy (EC, 2004b).

The concepts of diversity and subsidiarity are also important to consider in assessing the fragmented policy terrain of mountain areas. As noted in Chapter 3, Europe's mountain areas share common characteristics in terms of the existence of 'permanent natural handicaps' contributing to low economic density and relatively low accessibility. Yet in other crucial respects — for example, regarding environmental conditions, socioeconomic profile, and structural disparities — they exhibit significant diversity. Given these differing circumstances, the idea of a 'one size fits all' mountain policy is as unfeasible as it is undesirable. Moreover, the concept of subsidiarity — whereby decisions are taken as closely as possible to the citizen — is important in determining the competences and reach of EU policy in relation to the policy of Member States, and this extends to various policy sectors (such as forestry and tourism) as they relate to mountain areas.

1.2.2 Territorial cohesion and place-based mountain development

Both policy-makers and stakeholders need to manage a number of strategic issues in seeking to enhance sustainable development of mountain areas. These include:

- safeguarding the natural resources of mountain areas in ways that will sustain their vital ecosystem functions;
- addressing permanent natural handicaps to sustainable development linked to topographic and climatic barriers to economic activity and/or peripherality;
- tackling socioeconomic structural factors relating to demography, production and growth, labour market dynamics and accessibility that impede economic development and social cohesion.

Ongoing debate at the EU level regarding the scope and dimensions of territorial cohesion and the idea of a paradigm shift in rural development policy both have implications for evolving mountain policy approaches to address these strategic issues.

The European Commission has articulated the goal of territorial cohesion as being 'to encourage the harmonious and sustainable development of all territories by building on their territorial characteristics and resources' (EC, 2009a). Although it rules out linking territorial cohesion to geographical features that may influence development, the Commission confirmed support for the three basic elements proposed to achieve this goal:

- concentration (achieving critical mass while addressing negative externalities);
- connection (reinforcing the importance of efficient connections of lagging areas with growth centres through infrastructure and access to services);
- cooperation (working together across administrative boundaries to achieve synergies).

More broadly, the Organisation for Economic Co-operation and Development (OECD, 2006) has characterised an evolving approach to rural development, which it terms the 'new rural paradigm'. The key features of this approach include:

- rural competitiveness driven by local assets and resources, rather than relying only on agriculture;
- broadly based rural economies encompassing tourism, manufacturing and ICT;
- investment rather than subsidy; and
- the involvement of different levels of government and various local stakeholders.

The themes of territorial cohesion and place-based development, with their emphasis on maximising economic, social and environmental returns on local assets (natural and otherwise), are highly relevant to existing and potential policies and programmes relating to mountain areas in Europe.

A combination of climatic factors and structural disparities has exacerbated the marginalisation of mountain agriculture in some areas, leading to land abandonment with its attendant negative impacts for biodiversity, soil quality and landscape values, as discussed in Chapter 7 (EC, 2009b). Therefore, one important strand in the mountain development debate concerns how mountain farmers, in particular, can be paid for the ecosystem services that their agricultural practices (such as those relating to pastoralism and the seasonal movement of people with their livestock over relatively short distances, typically to higher pastures in summer and to lower valleys in winter) generate (Chapter 4). Closely related to this is the issue of how mountain communities should be compensated for the use of energy sources located in mountainous areas and how to optimise related market opportunities (Euromontana, 2010). A further related issue concerns the extent to which high-quality products (including food and crafts) directly relating to mountain assets and production processes can be turned to the competitive advantage of mountain producers by reflecting their added value in price (Robinson, 2009; Pasca *et al.*, 2009).

All these strands of debate on mountain development implicitly recognise the multifunctional dimensions of agriculture and forestry in mountain regions. There is further explicit recognition that harnessing these multifunctional dimensions and linking them to other sectors, such as tourism and recreation, can provide significant motors for the sustainable development of Europe's mountain areas.

A plethora of policy frameworks, institutional arrangements and instruments exist at various spatial levels. They address elements of the sustainable development of mountain areas, either specifically and exclusively or, more commonly, implicitly as one element of broader policy initiatives. The next three sections provide an overview of these at the EU national and sub-national, and regional levels.

1.2.3 Policy frameworks and instruments: the European Union

The policy competences with regard to agriculture, rural development, regional development and cohesion, and nature conservation within the EU have considerable influence on sustainable development of Europe's mountain areas, not only within Member States but also, to some extent, in other countries — as they harmonise their policies with those of the EU, for operational reasons and/or as a prelude to eventual membership.

Common Agricultural Policy and rural development

There is no specific overall EU mountain agriculture policy. Instead, interventions that shape the agricultural and related sectors within Europe's mountain areas mainly occur under the auspices of the Common Agricultural Policy (CAP) and, within that, the Rural Development Policy. Following CAP reform in 2003, its first pillar was redesigned to provide basic income support to farmers engaged in food production in response to market demand. Mountain farmers may be recipients of such support, although the low production levels of mountain agriculture place them at some disadvantage in this respect.

Pillar two of the CAP, the Rural Development Policy, was subject to reform in 2005, resulting in an increasingly strategic and administratively simplified approach to rural development, which focuses on the following three core objectives (EC, 2008):

- improving the competitiveness of agriculture and forestry;
- supporting land management and improving the environment;
- improving the quality of life and encouraging diversification of economic activities.

Support for rural development in 2007–2013 is provided through the European Agricultural Fund for Rural Development (EAFRD), which allocates funding to Member States through a variety of measures organised as follows:

- Axis 1 — Improving the competitiveness of the agriculture and forestry sector;
- Axis 2 — Improving the environment and the countryside through land management;
- Axis 3 — Improving the quality of life in rural areas and encouraging diversification of economic activity.

In addition, a fourth 'LEADER axis' supports individual projects designed and implemented by local partnerships to address specific local problems.

EU rural development measures have been targeted specifically at mountain regions since 1975 when a 'Mountain and Less Favoured Area' (LFA) (Directive 75/268 OJ No L128 of 19.05.1975 measure was introduced (see Chapter 7.4.1). This scheme, which is currently Measure 211 of Axis 2 of the Rural Development Policy, remains the key policy instrument for supporting mountain areas. Other measures in the Rural Development Policy may also be used by Member States to support activities in mountain areas as part of the general application of such measures. In addition to this wide-ranging approach, the Directorate-General for Agriculture and Rural Development suggests that there is also a general strategic trend of Member States supporting mountain farm/mountain rural diversification and the development of the forestry sector. Sixty Rural Development Programmes (RDPs) for 2007–2013 cover mountain areas, and a number of these implement measures that specifically address the situations of these areas (by assigning priority, awarding higher grants or defining specific actions). The implementation of these measures in relation to mountain areas is as follows (EC, 2009b):

- Measure 211 (Natural Handicap Payments in mountain areas) used in 60 RDPs;
- Measure 214 (Agri-Environment payments) used in 35 RDPs;
- Measure 121 (Modernisation of agricultural holdings) used in 27 RDPs;
- Measure 112 (Setting up of young farmers) used in 21 RDPs;
- Measure 311 (Diversification into non-agricultural activities) used in 19 RDPs;
- Measure 122 (Improvement of the economic value of forest) used in 17 RDPs;
- Measure 125 (Improving agriculture and forestry infrastructure) used in 16 RDPs;
- Measure 221 (First afforestation of agricultural land) used in 15 RDPs.

The concept of High Nature Value (HNV) farming, in which low-intensity farming has a vital role in European biodiversity conservation (Baldock, *et al.*, 1993), is highly relevant to mountain areas given the prevalence of such an approach in these areas (Section 7.4.2). Indeed, the EU Member States have committed themselves to three distinct actions regarding HNV farming (Beaufoy, 2008):

- identifying HNV farming;
- supporting and maintaining HNV farming, particularly through RDPs;
- monitoring changes to the area of land covered by HNV farming, and to the nature values associated with HNV farming, as part of Member States' monitoring of RDPs.

The European Commission appears confident that the existing policy framework is sufficiently comprehensive to enable agriculture in mountain areas to meet the various developmental challenges confronting the sector. However, it has expressed concern that understanding of problems, constraints, strategic priorities, approaches and methods of supporting mountain areas within the EU vary significantly within and between Member States (EC, 2009b). This suggests that there is potential for some Member States to more comprehensively analyse the developmental challenges and opportunities relating to agriculture in their mountain areas and recalibrate their application of RDP measures accordingly.

Forestry

The role of the EU in relation to forestry policy is limited by the subsidiarity principle and designed mainly to add value to national forest policies and programmes. This is done by:

- monitoring and possibly reporting on the state of EU forests;
- anticipating global trends and drawing Member States' attention to emerging challenges; and
- proposing and possibly coordinating or supporting options for early action at EU scale (EC, 2010a).

Despite the paramount importance of subsidiarity in shaping forestry policy within Member States, a strategic forestry policy framework does exist at EU level, together with specific policy instruments linking that framework to national and regional forestry policy contexts. The Forestry Strategy for the EU sets out sustainable forest management and multi-functionality as common principles of EU forestry (Council Resolution OJ 1999/C 56/01). The EU Forest Action Plan (2007–2011) sets out a coherent framework for forest-related activities at Community level and provides an instrument for coordinating Community initiatives within the forest policies of Member States. Its objectives include:

- improving long-term competiveness;
- improving and protecting the environment;
- contributing to a better quality of life;
- fostering communication and coordination.

These instruments, together with the Communication on Innovation and Sustainable Forest-based Industries (COM (2008) 113) reflect the multi-functionality of forests and resonate with the Lisbon and Gothenburg strategies of competitiveness and sustainable development. The need to manage the socioeconomic and environmental impacts of climate change in forests is addressed in a Green Paper titled *On forest protection and information in the EU: preparing forests for climate change* (EC, 2010a), which is linked to the framework of key actions contained in the EU Forest Action Plan (2007–2011)

(EC, 2007b). Other EU policies and instruments impact upon the forestry sector within Member States and are linked to key actions contained in the Action Plan. These include the Natura 2000 network (discussed in more detail in Chapters 8 and 9); EU climate policy (COM (2007)2/COM (2005) 35) and the Directive on promotion of energy from renewable resources (Directive 2009/28/EC).

Regional and cohesion policy
As noted in Section 1.2.3, a number of the European Commission's reports on economic and social cohesion specifically mentioned mountains among other areas with 'permanent natural handicaps', and this was again recognised in the Treaty of Lisbon. In general, regional and cohesion policy impacts upon Europe's mountain areas within the broader context of reducing economic and social disparities between regions across the EU and increasing the solidarity of EU citizens. The policy has three objectives: convergence; regional competitiveness and employment; and European territorial cooperation. These are implemented through the policy instruments of the European Regional Development Fund (ERDF), the European Social Fund (ESF) and the Cohesion Fund. Member States are able to target interventions on mountain areas that fall within the eligibility criteria associated with each of these objectives; often within the broader scope of their regional development strategies in relation to the 'convergence' and 'regional competitiveness and employment' objectives. However, the 'European territorial cooperation' objective includes programmes specifically aimed at mountain regions.

The convergence objective involves funding EU regions with GDP per capita of less than 75 % of the EU average — and also certain regions, some of which are mountainous, with an average GDP that is slightly above the 75 % threshold due to the statistical effect of EU enlargement — to support the modernisation and diversification of economic structures and to safeguard or create sustainable jobs. ERDF and/or ESF measures address a wide range of areas including research and development, risk management, education, energy, environment, tourism and culture. Additionally, the Cohesion Fund supports Member States whose Gross National Income (GNI) is 90 % per inhabitant of the Community average. This fund focuses on developing trans-European transport networks and projects that can demonstrate clear environmental benefits, for example relating to energy efficiency, renewable energy use and transportation.

The regional competitiveness and employment objective uses ERDF to support development programmes helping regions promote economic change through innovation and promotion of the knowledge society, environmental protection and improvement of accessibility. ESF support is applied to create more and better jobs through workforce adaptation and human resources investment. One example is given in Box 1.1. The territorial

Box 1.1 The Midi-Pyrénées Operational Programme

The Midi-Pyrénées Operational Programme is funded through the ERDF and has the following priorities:

Priority 1	Enhance the research potential of competitiveness poles and regional networks of excellence and modernise the higher education structures attached to them;
Priority 2	Develop competitiveness among businesses by means of a support policy focusing on aid for projects, innovation and raising the level of professionalism;
Priority 3	Preserve and enhance the environmental capital of the Midi-Pyrénées;
Priority 4	Boost the development of the Pyrenees via a balanced and sustainable inter-regional policy;
Priority 5	Improve accessibility, attractiveness and local transport;
Priority 6	Support urban projects on social cohesion and multi-modality;
Priority 7	Technical assistance.

Under the programme, the Ecovars project, undertaken by the Pyrenean Botanical Conservatory, was awarded EUR 47 580 to protect mountainous terrain from erosion and improve the local environment. This was done by replanting seeds at newly developed ski resorts and on the sides of newly built roads to protect and improve the Pyrenees by restoring its verdant alpine grasslands (EC, 2010a).

Source: Calum Macleod (Centre for Mountain Studies, Perth College UHI, the United Kingdom).

cooperation objective also uses ERDF to support cross-border cooperation through joint local and regional initiatives, trans-national cooperation in pursuit of integrated territorial development, and interregional cooperation and exchange of experience. Some, such as the Alpine Space Programme (Box 1.2), specifically concern mountain areas; others, such as the Northern Periphery Programme, include mountain areas, but are not specific to them.

Nature conservation and biodiversity

The Natura 2000 network of nature protection areas represents the main policy mechanism for nature conservation and biodiversity at EU level (Section 9.1). It aims to protect the most valuable and threatened species and habitats in Europe through designation of Special Areas of Conservation (SACs) by Member States under the 1992 Habitats Directive (92/43/EEC) (EC, 1992) and Special Protection Areas (SPAs) under the 1979 Birds Directive (79/409/EEC) (EC, 1979). The network also fulfils a Community obligation under the UN Convention on Biological Diversity.

The process of designating Natura 2000 network sites remains incomplete in a number of Member States, particularly those that have recently joined the EU. Nevertheless, it represents an important horizontal and vertical driver for sustainable development in the EU. This is because the network of Natura 2000 sites requires that development activities supported by EU instruments relating to agricultural, rural and regional policy meet the legislative requirements of the Habitats and Birds Directives, which underpin that network.

The challenge for policy-makers and other stakeholders is to ensure that the conservation objectives of Natura 2000 can be balanced with and used to reinforce wider economic development and social cohesion objectives. This challenge is particularly significant in relation to Europe's mountain areas given that, as shown in Section 9.1, 43 % of all EU-27 Natura 2000 sites are located in mountain massifs.

Wilderness

Considering the large proportion of Europe's wilderness in mountain areas (Section 10.3), the management of Europe's wilderness areas has significant implications for policy in relation to mountain regions. In February 2009, with an overwhelming majority the European Parliament passed a resolution calling for increased protection of wilderness areas in Europe. Subsequently in 2009, the Czech Presidency and the European Commission hosted a conference in Prague organised by the Wild Europe partnership on the theme of 'Wilderness and Large Natural Habitat Areas in Europe'. Over 240 delegates helped draft an agreement to further promote a coordinated strategy to protect and restore Europe's wilderness and wild areas. This includes the following elements:

- agreeing the definition and location of wild and nearly wild areas;

Box 1.2 The Alpine Space Programme

The Alpine Space Programme is an example of a transnational cooperation programme with a mountain area focus funded under this objective. The programme involves cooperation between Germany, France, Italy, Austria and Slovenia (with participation from Liechtenstein and Switzerland) and aims to enhance the competitiveness and attractiveness of the programme area by developing projects to meet the following four priorities:

- competitiveness and attractiveness of the alpine space;
- accessibility and connectivity;
- environment and risk prevention;
- technical assistance.

The programme anticipates over 150 small and medium-sized enterprises (SMEs) and research and technological development (R&TD) centres, 30 environmental authorities and non-governmental organisations (NGOs), and 10 transport authorities/mobility operators are expected to be involved in and benefit from the project activities. Results of the programme will be measured in terms of enterprise creation, employment rates, pollution levels, levels of environmental awareness and public investment generated (Alpine Space Programme, 2010).

Source: Calum Macleod (Centre for Mountain Studies, Perth College UHI, the United Kingdom).

- determining the contribution that such areas can make to halting biodiversity loss and supporting Natura 2000;
- recommendations for improved protection of such areas, within the existing legal framework;
- review of opportunities for restoration of large natural habitat areas;
- proposals for more effective support for such restoration;
- identifying best practice examples for non-intervention and restoration management;
- defining the value of low-impact economic, social and environmental benefits from wild areas.

Detailed outcomes from the Prague conference published in the agreement include a commitment to:

- compile a Register of Wilderness using existing databases, such as the EEA and World Database of Protected Areas (IUCN and UNEP-WCMC, 2010), identifying in tandem with appropriate interested parties the remaining areas of wilderness and wildlands, the threats and opportunities related to these, and their economic values, with practical recommendations for action; and
- complete the mapping wilderness and wildland areas in Europe, involving appropriate definitional and habitat criteria and level of scale to effectively support plans for protecting and monitoring such areas.

Other policies and initiatives
In addition to these five major policy areas of particular importance to mountain regions, there are many others, including:

- water: the Water Framework Directive (2000/60/EC) (EC, 2000a), given that Europe's mountains are the sources of most of the continent's rivers;
- climate change; the Strategy on climate change: the way ahead for 2020 and beyond (COM(2007)2) (EC, 2007a);
- environmental impact assessment and strategic environmental assessment: respectively, Directives 85/337/EEC (EC, 1985) (as amended by 97/11/EC [EC, 1997]) and 2001/42/EC (EC, 2001a);
- sustainable development: European Sustainable Development Strategy 2006 (10917/06) (EC, 2006).

Given the importance of Europe's mountains not only for mountain people, but as the source of many goods and services, both marketed and non-marketed — and the large range of interacting policies, with many possibilities for synergy, complementarity and contradiction — there have been calls for both a plan for the sustainable development of the EU's mountain regions (Committee on Agriculture and Rural Development, 2001) and for a 'full-scale Community regulatory and financial strategy' for mountain areas (Economic and Social Committee, 2002). In late 2006, the President of the European Commission indicated that he was in favour of the preparation of a Green Paper on future policy towards mountainous regions. However, this process has not proceeded.

1.2.4 Policy frameworks and instruments: national and sub-national

National legislation specifically targeted at mountain areas remains at an embryonic stage of development (Castelein *et al.*, 2006). To date, only six European countries — France, Greece, Italy, Romania, Switzerland and Ukraine — have mountain legislation in place; a bill for the development of mountain regions has also been drafted for Bulgaria, but has not been passed by the Parliament. There are several common characteristics in terms of developing and implementing such laws amongst these countries, including:

- a focus on promoting the socioeconomic development of mountain communities whilst simultaneously protecting the mountain environment, thereby framing policy within a sustainability perspective. For example, Article 1 of France's Mountain Act (Act 85-30 of 1985) stipulates that the policy must meet the environmental, social and economic needs of mountain communities whilst preserving and renewing their cultures;
- altitude as the main criterion for defining 'mountain' areas but with legislation also incorporating other criteria such as scarcity of arable lands (included in the Ukrainian legal definition of 'mountain settlements') and gradient of slopes (included in Romanian legislation defining mountain towns) and a wide range of other topographic and socioeconomic features;
- the establishment of institutions with special responsibilities for mountain development. For example, in Italy, Acts 1102 (1971) and 142 (1990) create and regulate 'Mountain Communities': decentralised and autonomous local bodies with a specific mandate to promote the development of their mountain areas;
- the promotion of economic activities in mountain zones through a range of policy

instruments including special funds, loans, subsidies and labelling schemes. For example, in Switzerland, Federal Act 901.1, 1997, on Aid to Investment in Mountain Regions, established a special federal fund to support infrastructure development in mountain regions. In France, Act 85–30 awards a special label to local products (usually crafts) from mountain areas as a quality guarantee and to promote local production;
- the pursuit of social objectives, especially in relation to improving infrastructure, education, health and other services. For example, Romania's Mountain Act of 2004 contains measures to promote mountain agriculture via on-farm training courses;
- protection of mountain environments, mainly through statutory provision for forest, soil and water resource conservation in mountain regions. For example, Italy's Mountain Act of 1994 contains specific provisions relating to mountain forest management, and France's Mountain Act of 2005 authorises mountain municipalities to use municipal tax revenues to fund soil erosion prevention schemes (Castelein *et al.*, 2006).

In contrast, there are many countries with mountains for which no mountain policies can be identified (EC, 2004b). These include:

- countries with very few or low mountains, where development policies are typically included in rural policies (for example, Belgium, Ireland and Luxembourg) or regional plans (for example, Poland);
- countries that are largely mountainous (for example, Greece, Norway and Slovenia) and mountain policy is effectively the same as general development policy.

In other countries, mountain policies are either sectoral or multi-sectoral (EC, 2004b). The first type principally comprises countries with middle mountains and new EU Member States. Most frequently, these policies are directed at the agricultural sector through LFA policies, and are often linked to environmental, rural development and tourism policies. The second type comprises countries where mountain policies are addressed to multi-sectoral development, beginning with mountain agriculture but also including other economic sectors (especially tourism), public infrastructure or services, and environment. Sectoral policies with specific adaptations address issues such as education, training, land use, regional development and spatial planning. Three federal countries — Austria, Germany and Spain — fit into this group; implementation is mainly at the provincial level. Austria has a relatively integrated policy with long-standing initiatives (1960 for agriculture, 1975 for global development).

There are also examples of sub-national arrangements within Europe, which mirror some of the characteristics identified at the national level above, including the High Mountain Law of the Province of Catalunya (Spain: Box 1.3) and the law for the Apuseni Mountains (Romania).

Box 1.3 Mountain policy in Catalonia, Spain

The Catalan Government passed its Mountain Act in 1983. The objectives of the Act include: to provide financial resources to ensure that living standards for inhabitants of mountain areas match the standards of citizens elsewhere in Catalonia; improving infrastructure provision in mountain areas; encouraging sustainable demography patterns in mountain areas; ensuring the sustainable development of mountain areas with reference to their historical, cultural and artistic heritage, preservation of environment and ecosystems and economic development priorities (particularly in relation to tourism, recreation and sport); and, creation of specific mountain agencies at district level.

Policy instruments for putting the objectives of the Act into practice include:

- the Mountain Regional Plan, designed as a comprehensive 5-year economic development plan which coordinates activities and investments of agencies of the government in each of the mountain counties;
- pluri-municipal zoning programmes of complementary actions aimed at resolving issues arising from mountain areas' geographical and socio-economic conditions;
- initiatives to offset social and economic imbalances in comparison to other areas of Catalonia, aimed at the agriculture sector.

Source: Calum Macleod (Centre for Mountain Studies, Perth College UHI, the United Kingdom).

1.2.5 Policy frameworks and instruments: regional

The Convention on the Protection of the Alps (Alpine Convention, 2005) and the Framework Convention on the Protection and Sustainable Development of the Carpathians (the Carpathian Convention) are the only two legally binding regional agreements specifically relating to mountain chains (Castelein *et al.*, 2006).

The Alpine Convention was adopted in 1991 and ratified by all nine of its signatories — Austria, France, the European Community, Germany, Italy, Liechtenstein, Switzerland, Slovenia and Monaco — by 1995. It provides for the protection and sustainable development of the Alps as a regional ecosystem with each of the signatories agreeing to develop a comprehensive policy in support of that objective. This policy is underpinned by the principles of prevention, 'polluter pays', and cooperation. As a framework convention, its application is through thematic protocols. Those on the following themes have been signed and ratified by most contracting parties: spatial planning and sustainable development; conservation of nature and landscape protection; mountain farming; mountain forests; tourism; energy; soil conservation; transport; and solution of litigation. Italy and Switzerland have still to ratify any of the protocols, and the European Union has yet to ratify five. There is a common understanding shared by the contracting parties not to elaborate further protocols, although important topics such as population and culture, and air pollution, are not covered in the nine protocols signed to date. For several years, the Alpine Convention has preferred to work with declarations and action plans, which, unlike protocols, are not legally binding.

In 2003, a Permanent Secretariat was established in Innsbruck, Austria, with a scientific office at the European Academy in Bolzano/Bozen, Italy (Alpine Convention, 2010). Two other structures have also developed as outcomes of the Convention: the Alpine Network of Protected Areas (ALPARC, 2010) and Alliance in the Alps (2010) an association of over 250 communities from all of the Alpine countries that 'strive to develop their alpine living environment in a sustainable way'. The Multi-Annual Work Programme 2005–2010 for the convention (Permanent Secretariat of the Alpine Convention, 2005) addressed the following key topics:

- mobility, accessibility, transit traffic;
- society, culture identity;
- tourism, leisure, sports;
- nature, agriculture and forestry, cultural landscape.

Each of these topics covers issues articulated in several protocols. Priority was given to issues that: firstly had a particular need for joint action; secondly, highlighted the interaction of different aspects of sustainable development; thirdly, were specific to the Alps; and fourthly, were likely to strengthen the sense of community in the Alps.

The Framework Convention on the Protection and Sustainable Development of the Carpathians (Carpathian Framework Convention, 2010) was signed in 2003 by the Czech Republic, Hungary, Poland, Romania, Serbia and Montenegro, Slovak Republic and Ukraine. Its general objectives are to 'pursue a comprehensive policy and cooperate for the protection and sustainable development of the Carpathians with a view to together improving quality of life, strengthening local economies and communities, and conservation of natural values and cultural heritage'. Following ratification by all countries, it came into force across the region in March 2008. The Convention foresees the adoption of specific protocols in different sectors; to date, a protocol on Conservation and Sustainable Use of Biological and Landscape Diversity (Biodiversity Protocol) has been adopted and will soon come into force. The Protocol on Sustainable Forest Management will be finalised soon, ready for approval by the Third Conference of the Parties to the Carpathian Convention in 2011. Pursuant to Article 4 of the Convention, the Carpathian Network of Protected Areas was established by the first meeting of the Conference of the Parties to the Carpathian Convention in December 2006 in Kyiv, Ukraine, as 'a thematic network of cooperation of mountain protected areas in the Carpathian Region'. The United Nations Environment Programme (UNEP) Vienna office serves as Interim Secretariat of the Convention. It supports its implementation and coordinates the thematic working groups established for the elaboration and implementation of the protocols and also promotes projects aiming at implementing the Convention (Box 1.4).

In addition to these two existing conventions, there have been initiatives to create others for two other mountain regions. In 2003, the presidents of Andorra and the regions in France and Spain that comprise the Working Community of the Pyrenees issued a declaration calling for a Convention of the Pyrenees following the model of the Alpine Convention (Treves *et al.*, 2002). There is a long history of trans-national cooperation in this region, with projects including the development of an interactive statistical atlas of the Pyrenees (CTP, 2010) There have also been initial discussions regarding a convention for the mountains of southeastern

Box 1.4 The Carpathian Space

One project coordinated by The United Nations Environment Programme (UNEP) Vienna office in its capacity as Interim Secretariat of the Carpathian Convention is the Carpathian Project (EU, 2010) under the Interreg IIIC Central European Adriatic Danubian South-Eastern European Space (CADSES) programme. This recognises that the Carpathian area may be defined in different ways. In addition to the mountain area, as defined for this report, most of the services serving the mountain population are located at the foot of the mountains. Beyond this is the wider region, including the NUTS 3 (in Ukraine NUTS 2) level administrative units to which the mountainous areas belong. Most statistical data and analyses — for example, in the Carpathians Environment Outlook 2007 (UNEP, 2007) — refer to these latter units. For the purposes of the analysis and strategy building in the region, this wider region has been delineated as the Carpathian programme area, or Carpathian Space. Its area is significantly greater (470000 km^2) than that of the Carpathian mountains (190 000 km^2). *Visions and strategies in the Carpathian Area* (VASICA) (Borsa *et al.*, 2009) is the first transnational spatial development document for the entire Carpathian Space and a core output of the Carpathian Project, representing a solid basis for future development of a comprehensive strategy for the Carpathian Space. One of the overall objectives of such a Carpathian Strategy is to ensure that sustainable development priorities of the Carpathian Space are fully included within and addressed by the future EU Danube Region Strategy and related high-level EU processes and programmes.

Source: Matthias Jurek (United Nations Environment Programme, Vienna, Austria).

Europe (Balkans), also supported by the UNEP Vienna office. In this context, to strengthen cooperation among the countries of the Dinaric Arc and Balkans, UNEP is leading the DABEO (Dinaric Arc and Balkans Environmental Outlook) process, aimed at elaborating an integrated environmental analysis of the region.

A further set of initiatives includes those linking protected areas across countries (Box 1.5; Section 9.3).

1.2.6 Conclusions

The sustainable development of Europe's mountain areas is dependent upon a complex web of public policies interacting, to a greater or lesser extent, at various scales ranging from the supra-national to the local. At the EU level, measures contained in the CAP, as they relate especially to the rural development component, are designed to enhance agricultural and forestry competitiveness, support land management and environmental improvement, and improve quality of life and the diversification of economic activities. Enhanced competitiveness leading to greater economic and social cohesion is also the overarching goal of regional policy. The direction of travel for both of these policy areas is towards the type of multi-sectoral, place-based development promoted in the OECD's 'new rural paradigm' (OECD, 2006) and towards promoting greater territorial cohesion within the EU based on concentration, connection and cooperation. This has important implications for mountain areas in terms of focusing policy attention and interventions on maximising opportunities to foster cross-sectoral linkages that can deliver on the economic, environmental and social components of sustainable development. In this respect, continuing to explore how multi-functional agriculture and forestry can contribute to economic diversification in mountain areas, whether through renewable energy supply, the provision of high-quality mountain products and services, or the provision of environmental public goods, represents a policy priority. More broadly, there are also important policy issues to consider regarding provision of transportation networks in mountain areas and their impacts upon accessibility and sustainability.

At the macro-regional, national and sub-national levels, a significant amount of political capital has been invested in developing policy frameworks and instruments designed to address the economic, environmental and social challenges associated with mountain development. There remains a need to evaluate the impact of these frameworks and interventions on the sustainability of mountain areas and disseminate findings widely, to aid the development of effective policy responses to ensure the sustainability of Europe's mountain areas and beyond.

1.3 Definitions of mountain areas

An evidence-based approach to decision- and policy-making requires agreement on the area for which such decisions and policies are being

Box 1.5 Dinaric Arc Initiative — a framework for sustainable development and conservation of the Dinaric Alps

The Dinaric Alps form the backbone of one of the most ecologically diverse regions in Europe, stretching from Italy through Slovenia, Croatia, Bosnia and Herzegovina, Serbia, Montenegro and Albania, with an area of approximately 100 000 km². Famous for its karstic geology, this is one of the most undisturbed mountain areas of Europe, hosting large and almost unspoilt forests as well as healthy populations of large carnivores such as bear, lynx, wolf and golden jackal. Within the Mediterranean basin, the eastern Adriatic area of the Dinaric Alps is the most water-rich area in terms of freshwater ecosystems.

This area has a rich and diverse cultural heritage, and a complex political history intertwined with recent conflicts and instability, in which the building of trust among nations needed to be re-established and improved. Small states and thus many borders, often along mountain ridges, call for transboundary cooperation to ensure the protection of the region's highly valued ecosystems, as well as cultural diversity. The Dinaric Arc Initiative (DAI) was established to facilitate dialogue between governments, NGOs and other relevant partners in the region, with the goal to promote favourable conditions for safeguarding the region's rich biological and cultural diversity.

The initiators of the DAI were WWF, International Union for Conservation of Nature (IUCN), and United Nations Educational Scientific and Cultural Organisation's (UNESCO) Regional Bureau for Science and Culture in Europe (BRESCE), which created an informal partnership in late 2004, and commenced a rapidly expanding initiative with important positive impacts in the region. The DAI now also includes United Nations Development Programme (UNDP), the Council of Europe, Food and Agriculture Organisation of the United Nations (FAO), UNEP, European Nature Heritage Fund (EuroNatur), Netherlands Development Organisation (SNV), Regional Environmental Center (REC) and European Centre for Nature Conservation (ECNC). These institutions chose to cooperate for the benefit of the region, adding value to each others' work by dealing with issues from different perspectives.

Starting with simple activities such as organising a capacity-building seminar for NGOs working in the Dinaric Alps to improve their communication and networking in protected areas (2005, led by IUCN), the DAI encouraged the development of a territorial plan for the Lake Skadar area between Montenegro and Albania (led by UNESCO BRESCE), which showed the way to designation of a protected area on the Albanian side. Other projects are being implemented. FAO has led on a project on the sustainable development of the Dinaric karst poljes in Croatia and Bosnia and Herzegovina, supporting rural development and integrated territorial management. IUCN has worked to develop a network of eco-villages in Montenegro, Serbia and Bosnia and Herzegovina. WWF started a large project 'Protected Areas for a Living Planet — Dinaric Arc ecoregion', focusing on the implementation of the Programme of Work on Protected Areas of the Convention on Biodiversity (CBD). The most recent project — Environment for People in the Dinaric Arc — is being implemented by IUCN, WWF and SNV to enhance local livelihoods and strengthen transboundary cooperation in six mountainous pilot sites.

At the 9th Conference of the Parties to the CBD in Bonn, Germany in 2008, the governments of Albania, Bosnia and Herzegovina, Croatia, Montenegro, Serbia and Slovenia signed a joint statement towards enhanced transboundary cooperation to safeguard natural and cultural values of the Dinaric region. This moved the governments closer to a vision of creating an ecological network of protected areas through the enlargement of nine existing protected areas and plans to create 13 new ones. It also represents an excellent basis for lasting regional cooperation in the region where geopolitical circumstances in the past led to the deterioration of mutual collaboration. The DAI partners will continue to develop innovative and effective approaches in facilitating dialogue among countries in the region, supporting governments and civil societies, empowering local communities, favouring the growth of national and local economies, and supporting sustainable management of resources and the preservation of biological and cultural diversity.

Source: Maja Vasilijevic (Transboundary Conservation Specialist Group, IUCN World Commission on Protected Areas, Croatia).

made. With respect to mountains this is not a simple process. While there is widespread agreement that the summits of high mountains are indeed mountains, there are contrasting opinions regarding both the difference between mountains and hills and, particularly, the lower extent of these topographical features of the landscape. In addition, as discussed below, delimitations do not necessarily use only topographical criteria; in particular, they may also be related to land use, such as for agriculture. More generally, specific mountain areas may also be linked to cultural identity (Granet-Abisset, 2004).

1.3.1 European and national definitions

Various definitions of mountain areas have been developed for the implementation of national and European policies. For the EU, Article 50 of Council Regulation (EC) No 1698/2005, on support for rural development by the European Agricultural Fund for Rural Development, includes the following definition of mountains, which is substantially similar to the definitions in the instruments it superseded:

> '2. In order to be eligible for payments provided for in Article 36(a)(i) mountain areas shall be characterised by a considerable limitation of the possibilities for using the land and an appreciable increase in the cost of working it due to:
>
> (a) the existence, because of altitude, of very difficult climatic conditions, the effect of which is substantially to shorten the growing season;
>
> (b) at a lower altitude, the presence over the greater part of the area in question of slopes too steep for the use of machinery or requiring the use of very expensive special equipment, or a combination of these two factors, where the handicap resulting from each taken separately is less acute but the combination of the two gives rise to an equivalent handicap.
>
> Areas north of the 62nd parallel and certain adjacent areas shall be regarded as mountain areas.'

In line with the principles of subsidiarity, EU Member States defined minimum altitudes and, in some cases slopes, to which these policy instruments applied (Table 1.1). However, in 2001, the Committee on Agriculture of the European Parliament took a more general view of mountain regions within the EU as: 'administratively distinct regions with over 50 % of the utilised agricultural area situated over 600 metres at least (if necessary with a higher limit up to 1 000 metres above sea level, depending on a specific number of days without frost) and with a shortened growing season… and also regions where the average degree of slope is over 20 %' (European Parliament, 2001).

The criteria in Table 1.1 show a decrease in the altitude threshold from south to north. This is primarily because such limits have largely been defined to identify areas to receive subsidies because of limits on agricultural productivity. Thus, this trend reflects the shorter growing season at higher latitudes. A comparable disadvantage is the reason why all land north of the 62nd parallel was included in the definition following the accession on Finland and Sweden to the EU, in recognition of the similarities between the constraints on agriculture in mountain and subarctic climates. In other countries, the agricultural mountain region covers 57 % of Bosnia and Herzegovina; mountains occupy 66 % of the former Yugoslav Republic of Macedonia (Price, 2000); and about two-thirds of Switzerland is defined as 'mountain' according to the 1974 federal law on investment in mountain regions (Castelein *et al.*, 2006). In summary, a considerable proportion of Europe has been designated as 'mountain' for various policies, largely in the context of agriculture. However, there is no consistency in the definitions.

1.3.2 Regional definitions

Two other definitions of mountain areas adopted for policy purposes appear in maps prepared to identify the extent of application of regional conventions. For the Alps, there is a map (Map 1.1) which is an annex to the Alpine Convention. According to this, the Alps include Monaco, but not the transport corridor directly to its north — a reflection of the difficult debate over transport corridors in the Alps which meant that the transport protocol to the Convention was one of the last to be negotiated (Price, 1999). For practical work, a preliminary list of municipalities (LAU 2) is used. For the Carpathians, following an exhaustive analysis of possible delimitations (Ruffini *et al.*, 2006), a specific boundary was used for the Carpathians Environmental Outlook 2007 (UNEP, 2007) (Map 1.2), though this boundary has not been formally agreed by all signatory states of the Carpathians Framework Convention.

1.3.3 The need for a consistent delineation of European mountain areas

In 1988, the Economic and Social Committee of the European Communities stated that 'an upland area [is] a physical, environmental, socio-economic and

Table 1.1 Criteria for definition of mountain area in European countries

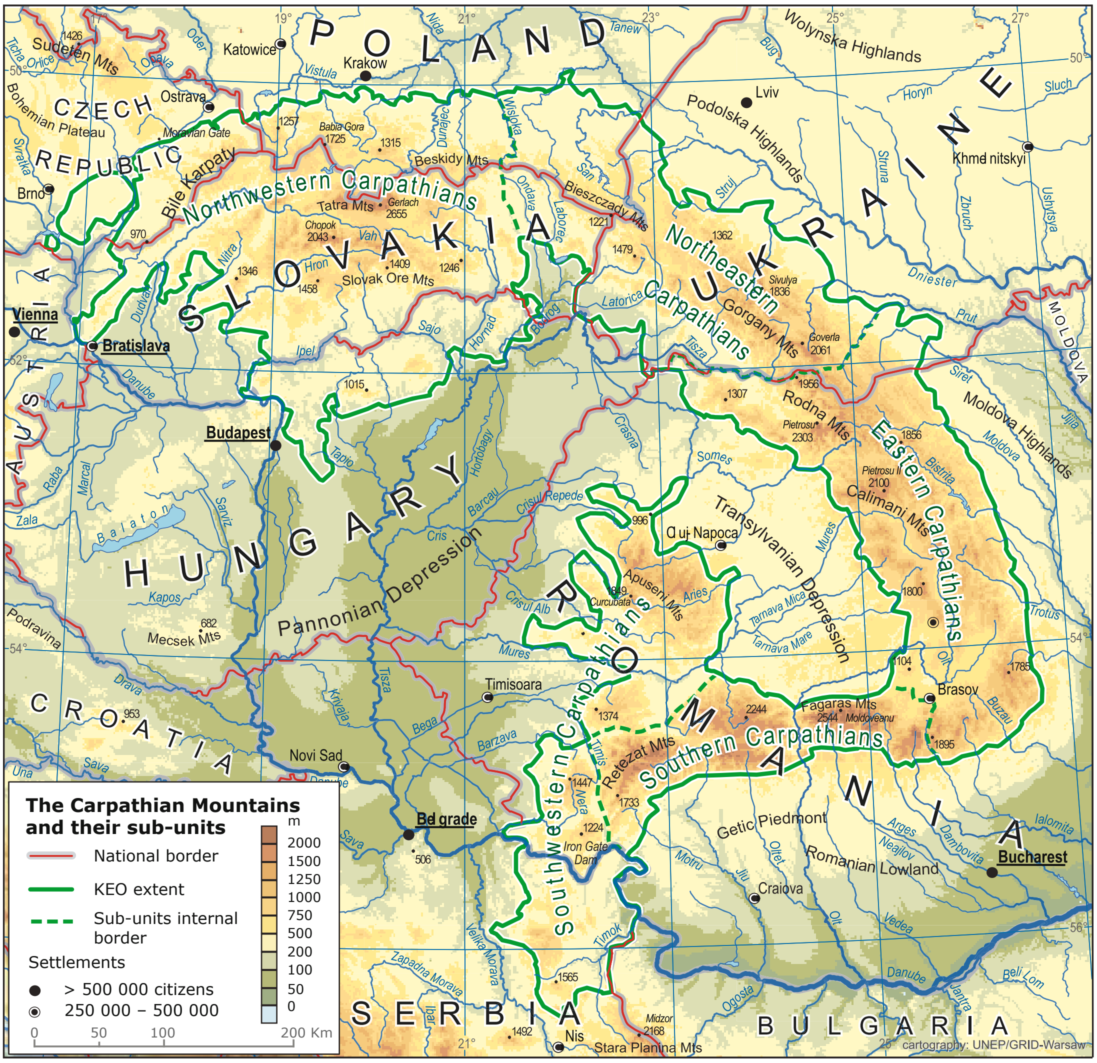
State	Minimum elevation	Other criteria
Albania	650 m	
Austria	700 m	Also above 500 m if slope > 20 %
Belgium	300 m	
Bulgaria	600m	Also > 200 m altitudinal difference/km^2; or slope > 12 °
Croatia	650 m	
Cyprus	800 m	Also above 500 m if average slope 15 %
Czech Republic	700 m	
France	700 m (generally) 600 m (Vosges) 800 m (Mediterranean)	Slope > 20 % over > 80 % of area
Germany	700 m	Climatic difficulties
Greece	800 m	Also 600 m if slope > 16 %; Below 600 m if slope > 20 %
Hungary	600 m	Also above 400 m if average slope > 10 %; or average slope >20 %
Italy	600 m	Altitudinal difference > 600 m
Norway	600 m	
Poland	350 m	Or > 12 ° for at least 50 % of agricultural land in a municipality
Romania	600 m	Also on slopes > 20 °
Slovakia	600 m	Also above 500 m on slopes > 7 °; or average slope > 12 °
Slovenia	700 m	Aalso above 500 m if more than half the farmland is on slopes of > 15 %; or slope > 20 %
Portugal	700 m (north of the Tejo river) 800 m (south of the Tejo river)	Slope > 25 %
Spain	1 000 m	Slope > 20 % Elevation gain 400 m
Ukraine	400 m	Also relating to scarcity of agricultural land and climatic conditions

Sources: Castelein *et al.* (2006); national reports for European Commission (2004b); European Observatory of Mountain Forests (2000); Price (2000).

Map 1.1 The Alps, as defined for application of the Alpine Convention

Source: Alpine Convention, Austria.

Map 1.2 The Carpathians, as defined for the Carpathians Environment Outlook 2007



Source: Carpathians Environment Outlook 2007. Provided courtesy of UNEP/DEWA-Europe and UNEP/GRID-Warsaw.

cultural region in which the disadvantages deriving from altitude and other natural factors must be considered in conjunction with socio-economic constraints, spatial imbalance and environmental decay' (Economic and Social Committee, 1988: 1). The Committee estimated that upland areas covered around 28 % of Community territory inhabited by about 8.5 % of the population. While this report did not provide a map of such 'upland areas', it is notable because the key issues which it identified went well beyond those related to agricultural production.

In the new century, a major emphasis of the work of the European Commission has been on social, economic, and territorial cohesion. In this, the Commission recognised three, often overlapping, types of region whose 'permanent natural handicaps' limit their potential for development in specific ways: mountain areas, territories with a low population density, and island territories. The Second Report on Economic and Social Cohesion (European Commission, 2001b: 35) noted that 'Mountainous areas represent geographical barriers… While some mountainous areas are economically viable and integrated into the rest of the EU economy, most have problems, as witnessed by the fact that more than 95 % of them (in terms of land area) are eligible for assistance under Objectives 1 or 2 of the Structural Funds'. The Third Cohesion Report (European Commission, 2004a: 31) noted that 'mountain areas are more dependent on agriculture than other areas particularly in the accession countries, but also in the EU-15. Although a number of mountainous areas are located close to economic centres and large markets, because of the terrain, transport costs tend to be high and many agricultural activities unsuitable. Unemployment tends to be higher in mountain areas which are the most peripheral.'

The Fourth Cohesion Report (European Commission, 2007c: 57) placed less of an emphasis on the 'handicaps' of mountain areas, stating that 'Although most mountain areas share common features such as sensitive ecosystems, pressure from human settlement and problems of accessibility, they are in fact extremely diverse in terms of socio-economic trends and economic performance… Similarly, traditional activities have tended to decline in some areas, while tourism has expanded, promoting economic development and providing job opportunities to the younger generation which was no longer obliged to leave in search of employment. In other mountain areas, however, productivity and employment have remained low and have shown little tendency in recent years to catch up. With economic development, however, pressure on the ecosystem of these regions has increased posing new threats to the environment. Mountain areas are also threatened by international road traffic, calling for solutions linking rail crossings to the road network. New opportunities may also be provided by modern telecommunications infrastructure, which — though slow to be installed largely because of the geographical features — can help to overcome many problems of accessibility which these regions face.' The need for special attention to mountain areas was formally recognised in article 174 of the consolidated version of the Treaty on the Functioning of the European Union, which states that 'particular attention shall be paid to rural areas, areas affected by industrial transition, and regions which suffer from severe and permanent natural or demographic handicaps such as the northernmost regions with very low population density and island, cross-border and mountain regions' (European Union, 2008).

In an expanding EU and in an increasingly complex continent the drive towards social and economic cohesion means that future policies for mountain areas should be based on thorough understanding of the social, economic, and environmental situation and the degree of success of past and current policies which directly or indirectly affect these areas. In this context, the European Commission's Directorate-General for Regional Policy (DG Regio) has recognised the need for statistical data to allow comparisons of the situation in mountain areas with national and European references and benchmarking the current situation for evaluation of the success of future policies. Consequently, DG Regio commissioned a study to provide an in-depth analysis of the mountain areas of all states that are now members of the EU: Norway and Switzerland joined the study at their own expense. The first objective of this study (European Commission, 2004b) was to develop a common delineation of the mountain areas of the 29 countries of the study area.

1.3.4 The delineation of European mountain areas using digital elevation models

The point of departure for the study was the global delimitation prepared by Kapos *et al.* (2000), using the GTOPO30 global digital elevation model (DEM) developed by the US Geological Survey. This study records the altitude of every square kilometre of the Earth's land surface in a database which was used to derive a detailed typology of mountains based on not only altitude, but also slope and terrain roughness (local elevation range, LER). Kapos *et al.* (2000) iteratively combined parameters from GTOPO30 to develop such a typology, starting from first principles and in consultation with scientists, policy-makers, and mountaineers. First, 2 500 m, the threshold above which human physiology is affected by oxygen depletion, was defined as a limit above which all environments would be considered 'mountain'. Second, they considered that at middle elevations, some slope was necessary for terrain to be defined as 'mountain', and that slopes should be steeper at lower elevations. Finally, the LER was evaluated for a 7 km radius around each target cell to include low-elevation mountains. If the LER was at least 300 m, the cell was defined as 'mountain'. According to this typology, 35.8 million km^2 (24 % of global land area) was classified as mountainous.

This work gave an area of nearly 1.7 million km^2 of mountains for the continent of Europe as far east and south as the Balkans and Carpathians, but not including the mountains of Turkey and Russia, or the Caucasus. However, while this global delineation is based on altitude and slope and has proved broadly acceptable to many international organisations and the scientific community, it does not include areas with marked topography at altitudes below 300 m. As mountains extend down to sea level in several parts of Europe, including the Iberian Peninsula, the British Isles, Greece, and Fennoscandia, a European delineation required a revision of the criteria of Kapos *et al.* (2000). Various combinations of altitude and topography and different ways of calculating the topographic element were tested. In addition, in a similar way to the inclusion of areas north of 62 °N in the definition of LFA mountain areas, DG Regio required the definition of not only mountain areas identified by their topographic characteristics, but also subarctic areas that are climatically equivalent. Consequently, an index based on average monthly minimum and maximum temperature data was used to identify mountain-like climates (European Commission, 2004b).

Sixteen combinations of criteria were produced to test different thresholds for altitude, climate, and topography. Their advantages and disadvantages were discussed with representatives of the European Commission and European organisations concerned with mountain issues, as well as national experts in the study team. The principal advance over the method used by Kapos *et al.* (2000) was the addition of a class of mountains below 300m. This identifies areas with strong local contrasts in relief, such as the Scottish and Norwegian fjords and Mediterranean coastal mountain areas. The best approach to including such landscapes was to calculate the standard deviation of elevations between each point of the DEM and the eight cardinal points surrounding it. If this is greater than 50 m, the landscape is sufficiently rough to be considered as 'mountain' despite the low altitude. For altitudes above 300 m, the following criteria were used:

- between 300 m and 1 000 m, areas which either meet the previously mentioned criterion or where altitudes encountered within a radius of 7 km vary by 300 meters or more are considered mountainous.
- between 1 000 m and 1 500 m, all areas which meet any of the previously mentioned criteria are considered mountainous. In addition to this, areas where the maximum slope between each point (to which value is assigned to) and the 8 cardinal points surrounding it is 5 ° or more are also considered mountainous.
- between 1 500 m and 2 500 m, in addition to all previous criteria, areas where the maximum slope between each point (to which value is assigned to) and the 8 cardinal points surrounding it is 2 ° or more are also considered mountainous.
- above 2 500 m, all areas are considered mountain.

1.3.5 *The delineation of European mountain areas for the present study*

For the present study, a very similar delineation was used, excluding the climatic criteria for areas north of 62 °N. Two further adjustments were made. First, isolated mountainous areas of less than 10 km^2 were not considered so as to create more continuous areas and considering that topographic constraints play a greater role when they extend over a certain area. Second, non-mountainous areas of less than 10 km^2 within mountain massifs were included. In the interests of a common approach across a topographically-complex continent it is recognised that this methodology leads to two counter-intuitive results. First, large high, but very low relief areas such as glaciated high plateaux and ice caps in the Nordic countries (predominantly Norway and Iceland) are not classed as mountains. However, given the aims of this study the exclusion of these areas is acceptable because these areas are uninhabited and, in the case of ice caps, have no human land uses and very limited biodiversity. Second, portions of steep river valleys in lowland areas are included, particularly in Sweden (due to postglacial uplift) and along the Danube (due to significant erosion). However, these linear features are easily identified and, in the next stage of analysis, easily excluded.

The distribution of mountain areas across the countries of Europe is shown in Table 1.2.

A further European level mountain data set was created for analysis, dividing the mountain area into massifs (or groups of massifs), as shown in Map 1.3. In all cases, the boundaries of massifs were drawn along the boundaries of NUTS 3 areas. Two of these massifs — the Alps and the Carpathians — are effectively those identified in relation to their respective conventions (cf. Maps 1.1 and 1.2). Similarly, the boundaries of the Pyrenees are generally agreed, for instance by the Working Community for the Pyrenees. The designation of the other massifs recognised the purpose of the subsequent analyses, and particularly the objective of addressing the outcomes of policy implementation.

1.3.6 *Biogeographic delineation of European mountains*

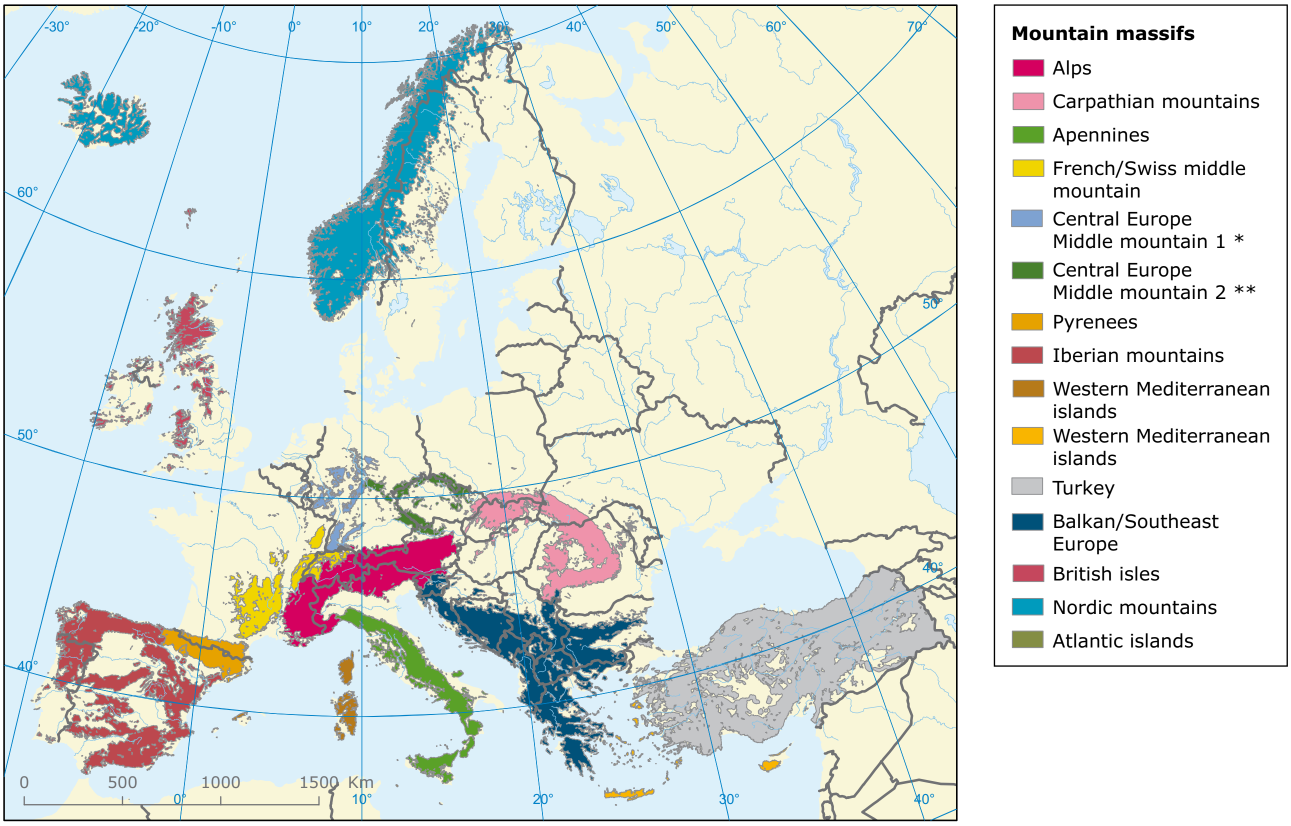
In addition to the delineations of mountains relative to agricultural productivity, the application of regional conventions, and topographic criteria, the European territory has been divided into nine biogeographic regions (Roekaerts, 2002) to quantify and report on various aspects of biodiversity with regard to the application of both the Habitats Directive and the Emerald network under the Bern Convention, particularly on numbers and trends in species, habitats, and protected areas. One of these is the Alpine biogeographic region, which covers 8.6 % of European territory (Sundseth, 2009). As shown in Map 1.4, this overlaps to a significant extent with the Carpathians, Alps and Nordic mountains, and

Table 1.2 Mountain areas across the countries of Europe

Country	National area (km²)	Mountain area (km²)	Mountain area %
European Union			
Austria	83 929	61 960	74
Belgium	30 663	1 340	4
Bulgaria	110 797	54 057	49
Cyprus	9 248	4 259	46
Czech Republic	78 866	25 668	33
Denmark	43 360		
Estonia	45 330		
Finland	337 797	5 031	1
France	549 169	137 524	25
Germany	357 678	57 764	16
Greece	132 021	94 886	72
Hungary	93 018	4 755	5
Ireland	70 177	10 096	14
Italy	301 424	181 150	60
Latvia	64 603		
Lithuania	64 892		
Luxembourg	2 596	212	8
Malta	316	35	11
Netherlands	37 357		
Poland	311 894	16 308	5
Portugal	92 187	34 980	38
Romania	237 948	90 094	38
Slovakia	49 026	29 454	60
Slovenia	20 274	15 378	76
Spain	505 964	274 613	54
Sweden	449 445	92 275	21
United Kingdom	244 722	60 689	25
European Union	**4 231 683**	**1 247 773**	**29**
Non-European Union			
Albania	28 531	23 002	81
Andorra	465	465	100
Bosnia And Herzegovina	51 275	40 379	79
Croatia	56 634	22 512	40
Former Yugoslav Republic of Macedonia	25 153	22 695	90
Iceland	102 907	67 413	66
Liechtenstein	161	161	100
Moldova	33 924	1 132	3
Montenegro	14 148	13 267	94
Norway	323 453	252 112	78
Serbia	88 428	47 035	53
Switzerland	41 288	38 806	94
Turkey	780 120	605 062	78
Ukraine	592 135	21 662	4
Europe	**6 672 759**	**2 409 601**	**36**

Source: Mountain massif delineation as defined for this study, country borders from EEAMapdata_5210_v2_3EEA16722I.

Map 1.3 Mountain massifs



Note: * = Belgium and Germany; ** = the Czech Republic, Austria and Germany.

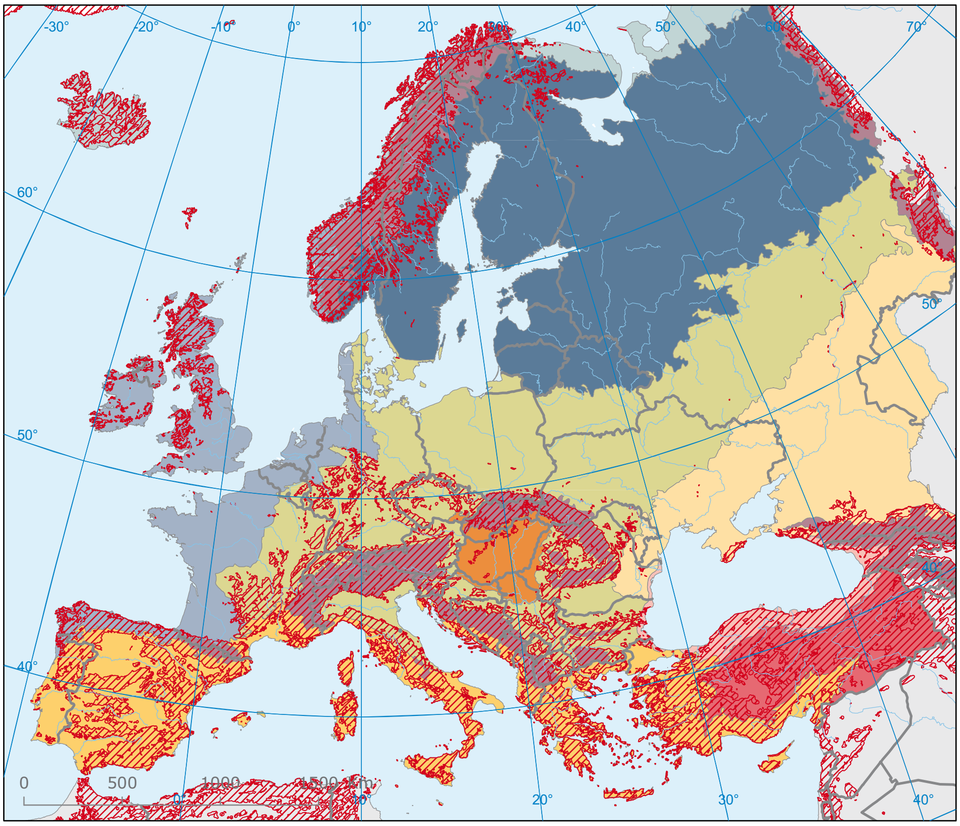
to a lesser extent in the Balkans/South-east Europe and Pyrenees, as well as the Apennines, where only the very highest parts are included. However, there is no overlap for other mountain areas, including the French/Swiss and Central European middle mountains, the Iberian mountains, or the mountains of Turkey, the British Isles, Iceland, and the Mediterranean islands.

1.4 Scales and scope of analysis

The evidence on which this integrated assessment is based is highly variable, with many information gaps. Comprehensive Europe-wide data sets of sufficiently detailed spatial resolution are currently available for only relatively few variables and topics and, in most cases, these are only for one point in time. For a few variables (e.g. population, land cover), data from two or more years are available, allowing trends to be identified and evaluated. For certain variables, comprehensive data sets are only available for the Member States of the European Union and; in some cases, only for the 15 States before enlargement in 2004. Specifically for biodiversity data, some analyses only address the Alpine biogeographic region, as described in Section 1.3.6 above. For some regions, notably the Alps (e.g. Tappeiner *et al.*, 2008), the Carpathians (e.g. UNEP, 2007) and the Pyrenees (e.g. http://atlas.ctp.org/site_fr/index_fr.php?lang=fr), the depth of usable information is greater than for Europe as a whole. For many regions, data are partial or only available at a relatively low level of spatial resolution. Consequently, throughout the report, many issues are illustrated through regional, national, or sub-national case studies provided by experts in their fields. As far as possible, these represent situations from across Europe's mountains.

Given the constraints in the availability of data and resources, the following chapters are of two types. Some — Chapters 2, 3, 7, 8, 9, and 10 — are principally based on analyses undertaken for this report. The other chapters are primarily based on literature reviews. The approach taken is to consider first the human systems of Europe's mountains: populations (Chapter 2), economies and accessibility (Chapter 3). Chapter 4 introduces the concept

Map 1.4 Biogeographic regions of Europe, with overlay of mountain area as defined for the present study



Biogeographic regions with overlay of mountain area

Mountains

Biogeographic region

- Alpine
- Anatolian
- Arctic
- Atlantic
- Black Sea
- Boreal
- Continental
- Macaronesia
- Mediterranean
- Pannonian
- Steppic
- Outside data coverage

of ecosystem services, stressing key interactions between human systems and other parts of the biosphere. Chapter 5 considers climate change, given the major challenges that it poses to all aspects of the mountain biosphere and the other systems to which they provide ecosystem services. Considering that the provision of water is probably predominant among these services, this is the subject of Chapter 6.

The three following chapters are linked, and address different elements of mountain ecosystems: land covers and uses (Chapter 7); biodiversity (Chapter 8); and protected areas (Chapter 9). Chapter 10 presents three integrated approaches to understanding mountain regions, and the concluding chapter discusses public policies relating to these regions.

2 Mountain people: status and trends

Human populations, whether resident in mountain areas, living near to them, or visiting as tourists, are major forces of environmental change in mountain areas. They are also influenced by environmental changes at all spatial and temporal scales. Mountain areas are often regarded as having low population densities. Although this may be true with regard to arithmetic density across an entire mountain region, a large proportion of the area is often unsuitable for human habitation for reasons of altitude, slope, exposure to natural hazards, or unsuitable substrate (rock, permafrost or ice), so the actual densities in the valleys where most mountain people live can be as high as in lowland areas. Such a 'physiological density' (Grötzbach and Stadel, 1997) may be more relevant for the people concerned and their impacts on their environment.

This chapter presents data on the numbers and density of Europe's mountain populations; and changes in the density of populations. The compilation of consistent demographic data across a large number of states is very challenging, as noted in the most recent report on Europe's mountains (European Commission, 2004). This also presents data and maps from the limited number of countries for which data were available, regarding depopulation, outmigration and the age structure of mountain populations, which represent linked key factors in economic and social trends. Rates of depopulation for the period 1991 to 2001 were generally higher in mountain than lowland areas; equally, many areas had experienced population growth, especially in many parts of the Alps. Outmigration was also generally higher from mountain areas except in France or Romania. Age structures (proportion of population below 15 and over 60) were highly variable at all spatial scales. Overall, this report concluded that 'very different process of demographic change are taking place in different parts of the European mountains' (European Commission, 2004: 87). Similar statements can also be made for the massifs for which data at a high spatial resolution are available, notably the Alps (Tappeiner *et al.*, 2008) and the Pyrenees (http://atlas.ctp.org/site_fr/index_fr.php?lang=fr).

2.1 Population numbers and density

The population data estimates for 2008 in the globally consistent Landscan data set, indicate that 118.4 million people live in the mountains of Europe: 17.1 % of the continent's population (Table 2.1). The Landscan data set is compiled on a 30' x 30' latitude/longitude grid, with census counts (at sub-national level) apportioned to each grid cell based on likelihood coefficients derived from proximity to roads, slope, land cover, night-time lights, and other information (Oak Ridge National Laboratory, 2010). It should be noted that, for most countries, the figures in Table 2.1 are lower than those presented in European Commission (2004), as this reported the populations in mountain municipalities, i.e. municipalities with at least 50 % of their area in mountain areas as defined in a similar way to this study. However, within these municipalities, many people often live on flatter land at lower altitudes and are therefore not included in the data in Table 2.1.

Mountain populations vary greatly at the national level. Turkey has by far the greatest mountain population at 33.4 million. This is more than twice the mountain population of the next highest, Italy (14.0 million). The three countries with the next largest mountain populations are also EU Member States: Spain (10.1 million), Germany (7.4 million) and France (6.5 million). Together, these four states account for 60 % of the mountain population of the EU-27. The EU Member States of Romania (4.6 million) and Austria (4.0 million) are also among the ten countries with the largest mountain population; as well as the non-EU countries in this study — Turkey, Switzerland (6.3 million), Serbia and Montenegro (3.2 million), and Bosnia and Herzegovina (2.7 million).

Certain groups of countries stand out as having particularly high proportions of the total population living in mountain areas. Of these ten countries have at least half their population living in mountain areas: is found in Andorra, in the Pyrenees (100 %); Liechtenstein (99 %), Monte Carlo (89 %) and Switzerland (81 %) in the Alps; the Faroes (82 %) and San Marino, in the Apennines (72 %); the

Table 2.1 Population number and density in and outside mountains, and at national level, for all European states, 2008

	Total population in Massifs	% of total population in massifs	Population density in massifs (per km²)	Population density outside massifs (per km²)	National population density (per km²)
Austria	3 978 149	48.4	64.2	192.9	97.9
Belgium	65 698	0.6	49	352.6	339.3
Bulgaria	2 565 509	35.9	47.5	80.8	64.5
Cyprus	51 894	6.6	12.2	146.9	84.9
Czech Republic	2 137 409	20.9	83.3	151.9	129.6
Denmark	0	0	0	125.2	125.2
Estonia	0	0	0	28.7	28.7
Finland	2 443	0.1	0.5	15.6	15.4
France	6 454 677	10.4	46.9	134.6	112.7
Germany	7 403 687	9.0	128.2	249.8	230.2
Greece	2 612 508	24.8	27.5	213.2	79.8
Hungary	293 163	2.9	61.7	109.2	106.8
Ireland	115 924	2.8	11.5	66.7	58.7
Italy	14 023 306	24.4	77.4	361.5	190.7
Lithuania	0	0	0	55	55.0
Luxembourg	20 488	4.2	96.6	195.3	187.2
Latvia	0	0	0	34.8	34.8
Malta	11 846	3.1	341.5	1 323.8	1 215.9
Netherlands	0	0	0	445.5	445.5
Poland	1 986 144	5.2	121.8	123.5	123.4
Portugal	2 173 407	20.6	62.1	146.5	114.5
Romania	4 553 602	20.6	50.5	119.1	93.1
Slovakia	2 111 904	38.7	71.7	170.9	111.3
Slovenia	1 010 649	50.6	65.7	201.7	98.6
Spain	10 066 698	25.2	36.7	129.2	79.0
Sweden	78 549	0.9	0.9	24.6	19.8
United Kingdom	1 345 968	2.2	22.2	322	247.7
EU-27	**63 063 622**	**13**	**50.3**	**137.8**	**112.5**
Albania	1 416 416	39.8	61.6	387	124.6
Andorra	82 627	100	177.8	0	177.8
Bosnia and Herzegovina	2 670 714	58.3	66.1	175	89.3
Belarus	0	0	0	222	222.0
Croatia	585 222	13.2	26.0	112.6	78.2
Faroe Islands	27 651	82	26.3	20.2	24.9
Gibraltar	7 319	34.9	1 653.9	10 254.9	3 643.9
Iceland	25 875	8.9	0.4	7.4	2.8
Liechtenstein	33 985	99	211.7	0	213.7
Former Yugoslav Republic of Macedonia	1 369 141	66.6	60.3	279.3	81.7
Moldova	146 685	3.4	129.6	126.3	126.4
Monte Carlo	25 696	88.8	15 131.9	238 992.1	16 906.0
Norway	1 305 841	29.6	5.2	43.6	13.7
San Marino	20 901	71.9	430.5	623.5	471.5
Serbia and Montenegro	3 169 008	32.0	52.6	159.2	96.5
Switzerland	6 169 388	81.1	159.0	579.6	184.3

Table 2.1 Population number and density in and outside mountains, and at national level, for all European states, 2008 (cont.)

	Total population in Massifs	% of total population in massifs	Population density in massifs (per km²)	Population density outside massifs (per km²)	National population density (per km²)
Turkey	33 394 686	46.9	55.2	216.2	91.3
Ukraine	1 065 171	2.3	49.2	77.6	76.5
Vatican	211	25.6	573.9	1 267.7	968.1
Non-EU	**51 516 537**	**25.2**	**44.5**	**127.6**	**86.8**
Europe	**114 580 159**	**16.6**	**47.6**	**134.9**	**103.4**

former Yugoslav Republic of Macedonia (66.6 %) and Bosnia and Herzegovina (58.3 %) in southern Europe and Slovenia (50.6 %) and Austria (48.4 %) in the Alps. Turkey also has a high proportion of its population in mountain areas — 46.9 %. At the other end of the spectrum, the United Kingdom (2.2 %), Ukraine (2.3 %) and Poland (5.2 %) are countries with a mountain population of more than 1 million where this represents a particularly low proportion of total population. Thus, when comparing different parts of Europe, while only 13 % of the total population of the EU-27 lives in mountain areas, over a third of the population in the candidate and potential candidate countries of south-eastern Europe live in mountain areas — 44 % including Turkey, 38 % without Turkey.

The highest population densities in mountain areas are found in small states, most of which also have high proportions of their population living in the mountains, notably Monte Carlo — the most densely populated state in Europe — as well as San Marino, Liechtenstein and Andorra. Except for such small countries, mountainous parts of countries are always less densely populated than the lowlands. Nevertheless , the difference is not very large for some countries with mountain populations of over a million: Poland (122 people/km²) in mountain areas; 123 in lowlands), Ukraine (49; 77), Bulgaria (47; 81), and Croatia (52; 95). Of those countries with mountain populations of over a million, Switzerland has the highest population density in its mountains: 159 people/km²). The only other countries with large mountain populations and mountain population densities greater than 100 people/km² are Germany (128) and Poland (122). The countries with the lowest mountain population densities are all Nordic countries: Iceland (0.4 people/km²), Finland (0.5), Sweden (0.6) and Norway (5.2).

Many of the analyses in this report refer to populations in the massifs presented in Map 1.3. Table 2.2 presents the populations of each massif, and Map 2.1 shows how the populations of these massifs are distributed between their constituent countries.

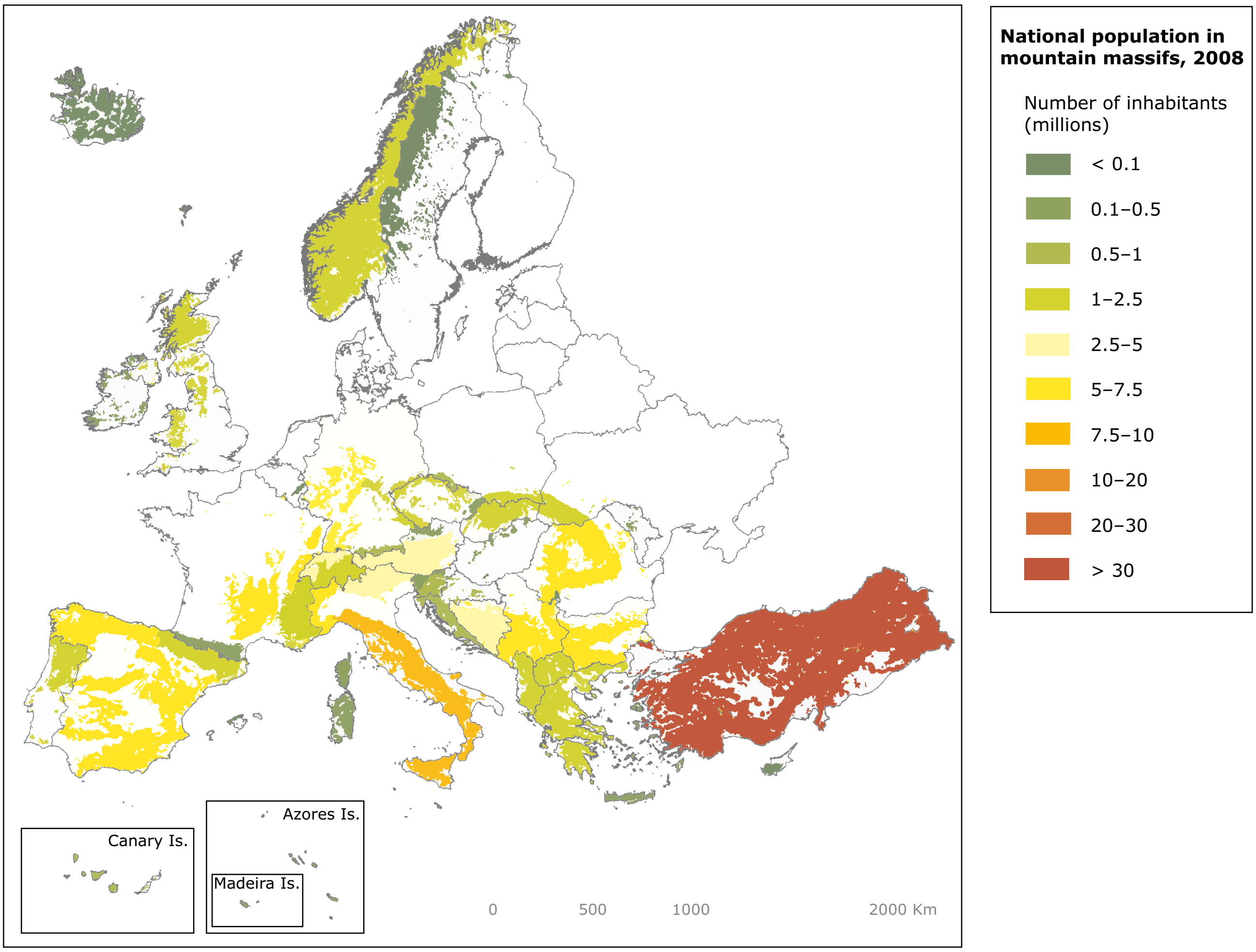
The massif with the largest population is Turkey. The massif with the next largest population is the Balkans/South-east Europe, with 22 % of its population in Serbia and Montenegro, 18 % in Bosnia and Herzegovina, 17 % in Bulgaria, 15 % in Greece, 10 % in Albania, and 9 % in the former Yugoslav Republic of Macedonia. The population of the Alps is slightly smaller, with 30 % in Italy, 26 % in Austria, and 18 % in France and in Switzerland. Almost half of the population of the Carpathians (45 %) is in Romania; with Slovakia (22 %), Poland (14 %), and Ukraine (10 %). In the Iberian mountains, 79 % of the population is in Spain, which also includes 81 % of the population of the Pyrenees and 78 % of the population of the Atlantic Islands. The population of the French/Swiss middle mountains (Map 1.3) are almost evenly divided between Switzerland (51 %) and France (49 %). Most of the population of the Central European middle mountains 1 (Map 1.3) is in Germany (97 %). In the neighbouring Central European middle mountains 2 (Map 1.3), proportions are similar in the Czech Republic (41 %) and Germany (38 %). In the mountains of the British Isles, most of the population is in the United Kingdom (90 %). Of the population of the Nordic mountains 92 % is in Norway. The majority of the population of the western Mediterranean islands is in Italy (Sardinia 72 %). As shown in Figure 2.1, the density of population varies considerably across the massifs, being particularly high in the central European middle mountains and Atlantic islands. Conversely, population densities are particularly low in the mountains of the British Isles and, especially, the Nordic mountains — the most sparsely populated parts of sparsely-populated countries.

Table 2.2 Population of mountain massifs, 2008

Massif	Population
Alps	14 037 794
Apennines	9 436 724
Atlantic islands	1 000 181
Balkans/South-east Europe	14 636 605
British Isles	1 489 543
Carpathians	9 966 351
Central European middle mountains 1 (Belgium and Germany)	5 164 949
Central European middle mountains 2 (the Czech Republic, Austria and Germany)	4 203 715
Eastern Mediterranean islands	462 311
French/Swiss middle mountains	7 069 632
Iberian mountains	9 155 253
Nordic mountains	1 412 708
Pyrenees	2 503 926
Turkey	33 394 686
Western Mediterranean islands	645 781

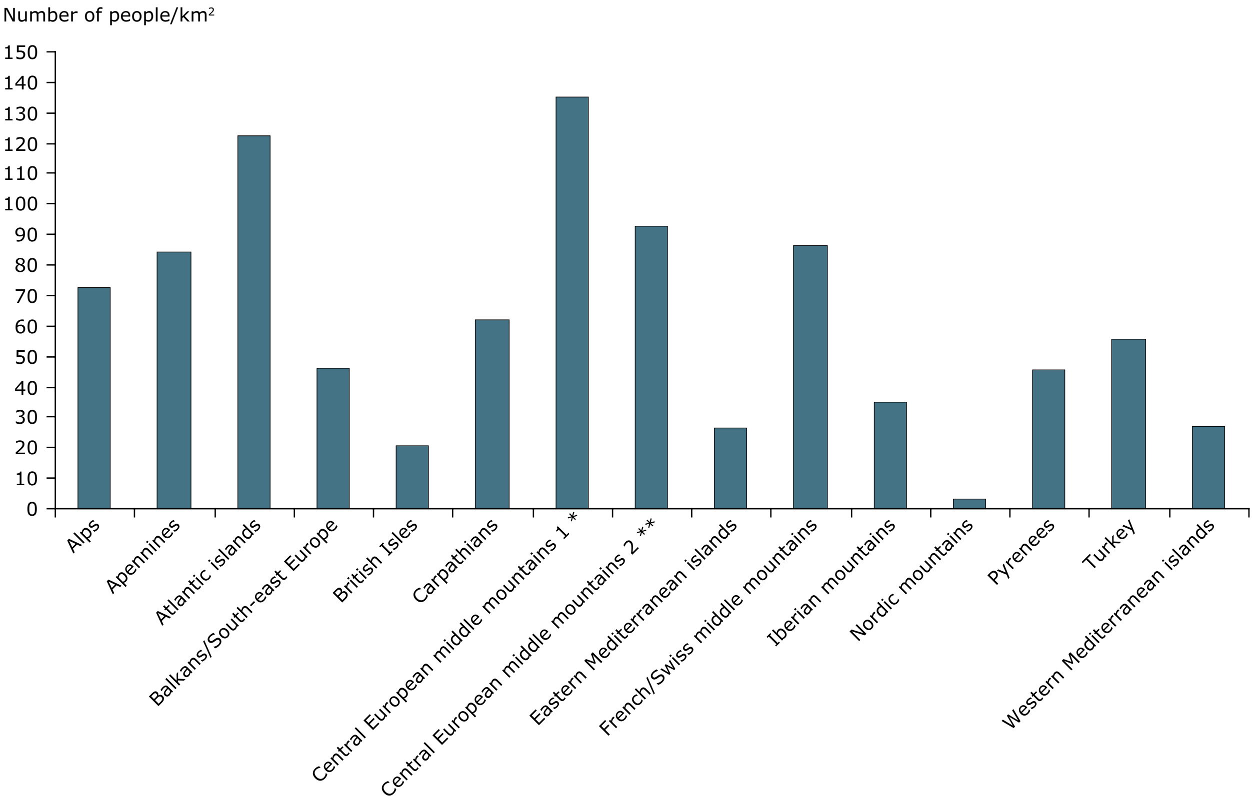
Source: LandScan™ Global Population Database. Oak Ridge, TN: Oak Ridge National Laboratory. Available at www.ornl.gov/landscan/. Mountain massif delineation as defined for this study.

Map 2.1 National population in mountain massifs, 2008



Source: LandScan™ Global Population Database. Oak Ridge, TN: Oak Ridge National Laboratory. Available at www.ornl.gov/landscan/. Mountain massif delineation as defined for this study.

Figure 2.1 Population density in mountain massifs, 2008



Note: * = Belgium and Germany; ** = the Czech Republic, Austria and Germany.

Source: LandScan™ Global Population Database. Oak Ridge, TN: Oak Ridge National Laboratory. Available at www.ornl.gov/landscan/. Mountain massif delineation as defined for this study.

2.2 Trends in population density

For centuries, economic and political changes, often involving wars and forced changes of population in their aftermath, have had major influences on the mountain populations of Europe, as exemplified by the case of Greece (Box 2.1). In recent decades, significant economic and political changes, particularly in the former socialist countries, have interacted with longer-term factors of demographic change to result in populations described in Section 2.1. Changes in population for the mountains of most of the EU-27, Norway and Switzerland, derived from national data, have previously been presented and discussed in European Commission (2004). This section presents changes in population density in the period from 1990 to 2005, using the Gridded Population of the World dataset (version 3) (Balk and Yetman, 2004). This is a globally consistent dataset, at a resolution of 2.5 arc minutes, based on the national censuses conducted around the year 2000 and in earlier years, and also includes estimates for the year 2005.

Table 2.6 and Figure 2.2 present annual changes in population density by massif for the periods 1990–2000 and 2000 to 2005. Overall, there was a considerable increase in population density across Europe's mountains, although the patterns differ between the massifs. The differences cannot be described easily either by geographic location or by former political status. Population density increased in both time periods in the Alps, French/Swiss middle mountain, Nordic mountains, and the mountains of the British Isles, Turkey and western Mediterranean islands. Population density decreased in both time periods, in the Apennines, Atlantic islands and Central European middle mountains 2.

In the other massifs patterns differ between the two periods. In the Balkans — South-east Europe and Carpathians, population densities decreased from 1990 to 2000 and increased from 2000–2005. However, the latest increase in the Balkans did not compensate for the previous decrease (see last column of Table 2.6). The opposite occurred in the Central European middle mountains 1, Eastern

Box 2.1 Population shifts in the mountains of Greece

While relics of ancient settlements can be found in many of the mountains in Greece, their population first increased markedly from the 15th to the 19th Centuries, while the Ottoman Empire was dominant. To control the mainland and the coastline, the Ottomans preferred to settle urban centres. Consequently, the Greeks, searching for protection and safety, moved to the mountains creating small settlements that evolved into well organised villages.

The Ottoman Empire also developed inland European commercial routes as part of their strategy to compete with Venice that dominate the seas as the world commercial power of the Thus, Greek highlanders were employed to travel through the almost pathless mountains, and many Greek villages gained special privileges and a certain level of independence. Greek merchants from these villages travelled all over Europe and elsewhere. These villages reached their peak of development in the 18th century, and continued to evolve until the mid-20th Century, though at a lower rate., Four successive shocks then hit mountainous Greece. The first was World War II, which took place mainly in the mountains as the main theatre of operations and of the Greek Resistance. As a result mountain communities suffered many environmental and economic losses.

Massive depopulation followed in the post-war years due to the Civil War (1946–1949), followed by emigration and mass urbanisation. During the Civil War, almost 800 000 mountain people were forced to move to the lowlands in order to cut off supplies to the combatants (Louloudis, 2007). The former inhabitants were able to return to their places of origin from 1950 onwards but very few chose to abandon their way of life for a second time. After the War, poverty and unemployment led many thousands to search for a better life, both in urban centres and abroad. The mountainous population of North Greece alone was reduced by 23 % from 1940 to 1951 (Table 2.3).

Table 2.3 Population fluctuations (%) in mountainous areas of North Greece, 1940–2001

<table>
<tr><th>Years</th><th>1940–1951</th><th>1951–1961</th><th>1961–1971</th><th>1971–1981</th><th>1981–1991</th><th>1991–2001</th><th>1940–2001</th></tr>
<tr><td>Epirus</td><td>– 26.59</td><td>– 3.05</td><td>– 25.77</td><td>7.11</td><td>– 10.91</td><td>+ 14.70</td><td>– 42.17</td></tr>
<tr><td>West Macedonia</td><td>– 18.65</td><td>0.25</td><td>– 14.07</td><td>7.77</td><td>– 0.39</td><td rowspan="2">+ 16.40</td><td rowspan="2">– 15.78</td></tr>
<tr><td>Central Macedonia</td><td>– 33.00</td><td>11.85</td><td>– 27.05</td><td>– 15.23</td><td>12.45</td></tr>
<tr><td>East Macedonia and Thrace</td><td>– 36.25</td><td>0.82</td><td>– 23.37</td><td>– 10.48</td><td>– 7.35</td><td>+ 0.22</td><td>– 50.05</td></tr>
<tr><td>North Greece</td><td>– 22.90</td><td>0.43</td><td>– 18.17</td><td>4.98</td><td>– 2.00</td><td>+ 16.31</td><td>– 24.17</td></tr>
</table>

During this decade, Epirus, the most mountainous Greek region, lost almost 30 % of its population, and other mountainous regions — East Macedonia-Thrace, Central Macedonia and West Macedonia — lost 36 %, 33 % and 19 % of their population respectively (Karanikolas et al., 2002). From 1951 to 1961, some regions experienced a small population increase: e.g. 12 % in Central Macedonia (Table 2.4).

Table 2.4 Mountain population of peripheral areas and North Greece, 1940–2001

<table>
<tr><th>Year</th><th>1940</th><th>1951</th><th>1961</th><th>1971</th><th>1981</th><th>1991</th><th>2001</th></tr>
<tr><td>Epirus</td><td>110 484</td><td>81 111</td><td>78 636</td><td>58 374</td><td>62 527</td><td>55 708</td><td>63 893</td></tr>
<tr><td>West Macedonia</td><td>292 217</td><td>237 708</td><td>238 307</td><td>204 771</td><td>20 676</td><td>219 811</td><td rowspan="2">West and Central 280 813</td></tr>
<tr><td>Central Macedonia</td><td>41 249</td><td>27 636</td><td>30 912</td><td>22 549</td><td>19 114</td><td>21 494</td></tr>
<tr><td>East Macedonia and Thrace</td><td>31 254</td><td>19 925</td><td>20 089</td><td>15 395</td><td>13 781</td><td>12 768</td><td>15 610</td></tr>
<tr><td>North Greece</td><td>475 204</td><td>366 380</td><td>367 944</td><td>301 089</td><td>316 098</td><td>309 781</td><td>360 316</td></tr>
</table>

The 1960s were a decade of mass urbanisation. The two main urban centres, Athens and Thessaloniki, attracted the majority. Already impoverished mountain villages again lost their inhabitants, especially the young. Older people remained behind, unwilling to give up the familiar way of life. In the early 1980s, mountainous Greece appeared poor and devastated compared to the vivid and rapidly developing urban centres. Overall, the population of Greece living in mountain areas decreased from 12 % in 1971 to 9 % in 2001 (Table 2.5). Epirus and Macedonia, the most mountainous peripheral areas, were severely depopulated, losing half of their population.

Box 2.1 Population shifts in the mountains of Greece (cont.)

Table 2.5 Population fluctuations in Greece, 1951–2001

Year	1951	1961	1971	1981	1991	2001
	Population					
Semi mountainous areas (total Greece)	1 341 850	No available data	1 781 689	2 085 961	2 236 351	2 318 717
Mountainous areas (total Greece)	1 069 470		1 047 894	941 586	939 843	935 585
% of national population in mountainous areas	14		12	10	9	9

Depopulation of mountain regions continued throughout the 1980s (1981–1991), though at a lower rate. Populations have increased from 1991 to 2001 (Matsouka and Adamakopoulos, 2007), mainly due to internal migration and a growing interest in mountain areas. People have seemed to rediscover mountains, attracted by their unspoiled nature and the quality of life they offer. Tourism has been linked to the restoration of old buildings and the construction of new ones in mountain villages. During the last decade, a significant number of migrants (7 % of the total Greek population) moved to the mountainous regions, forming a population injection for many depopulated villages. Job opportunities in building, road construction and cattle-breeding keep immigrants in the mountains, preventing many schools from closing down and revitalising the villages.

Source: Dimitris Kaliampakos and Stella Giannakopoulou (National Technical University of Athens, Greece).

Mediterranean islands, Iberian mountains and Pyrenees. Overall, the net changes in population density for the entire period 1990–2005 varied considerably between the massifs.

Changes in population density were not only different between the different massifs but there were also differences by country within the same massif (Table 2.7). At the national level, there is a consistently increasing trend in mountain population density in s is the British Isles, the Pyrenees, the eastern Mediterranean islands and Central European middle mountains 1. However, for the other massifs, trends varied between countries. In the Balkans/South-east Europe, densities increased considerably in Croatia and the former Yugoslav Republic of Macedonia, decreased considerably in Albania, Bulgaria and Romania, and changed little in Greece and Slovenia. In the Carpathians, densities decreased except in Poland and Slovakia. In Poland and Slovakia, this reflects the fact that the mountain area as defined for this report includes basins between mountains where the populations of smaller towns and cities increased, whereas, the population density in the other mountains of Poland (Central European middle mountains 2) decreased. A comparable pattern is evident for Germany, where the density in the middle mountains decreased, but the density in the Alps increased. Similarly population densities in the Italian Alps increased in contrast to a decreasing trend in other parts of Italy including the Apennines and Sardinia (western Mediterranean islands). Densities increased in all French and Spanish mountains, the two other countries whose mountains are divided between a number of massifs.

A key issue here is the extent to which the changes in massifs, and parts of massifs, reflect national trends. To help resolve this question, population density changes inside and outside the mountain massifs per country are shown in Table 2.8. In general, the trends in population density observed in the mountains are consistent with the trends observed in the rest of the country. However, in Switzerland, Finland, Poland, Portugal, Serbia, Sweden and Slovenia the trends in mountain areas are the opposite of those in the rest of their respective countries. The population density increased outside the mountains and decreased inside the sparsely-populated mountains of Finland and Sweden; a similar pattern was shown in Portugal and Italy, but the changes are smaller.

Table 2.6 Population density change for the time periods 1990–2000, 2000–2005 and 1990–2005 (inhabitants per km² and in % per massif)

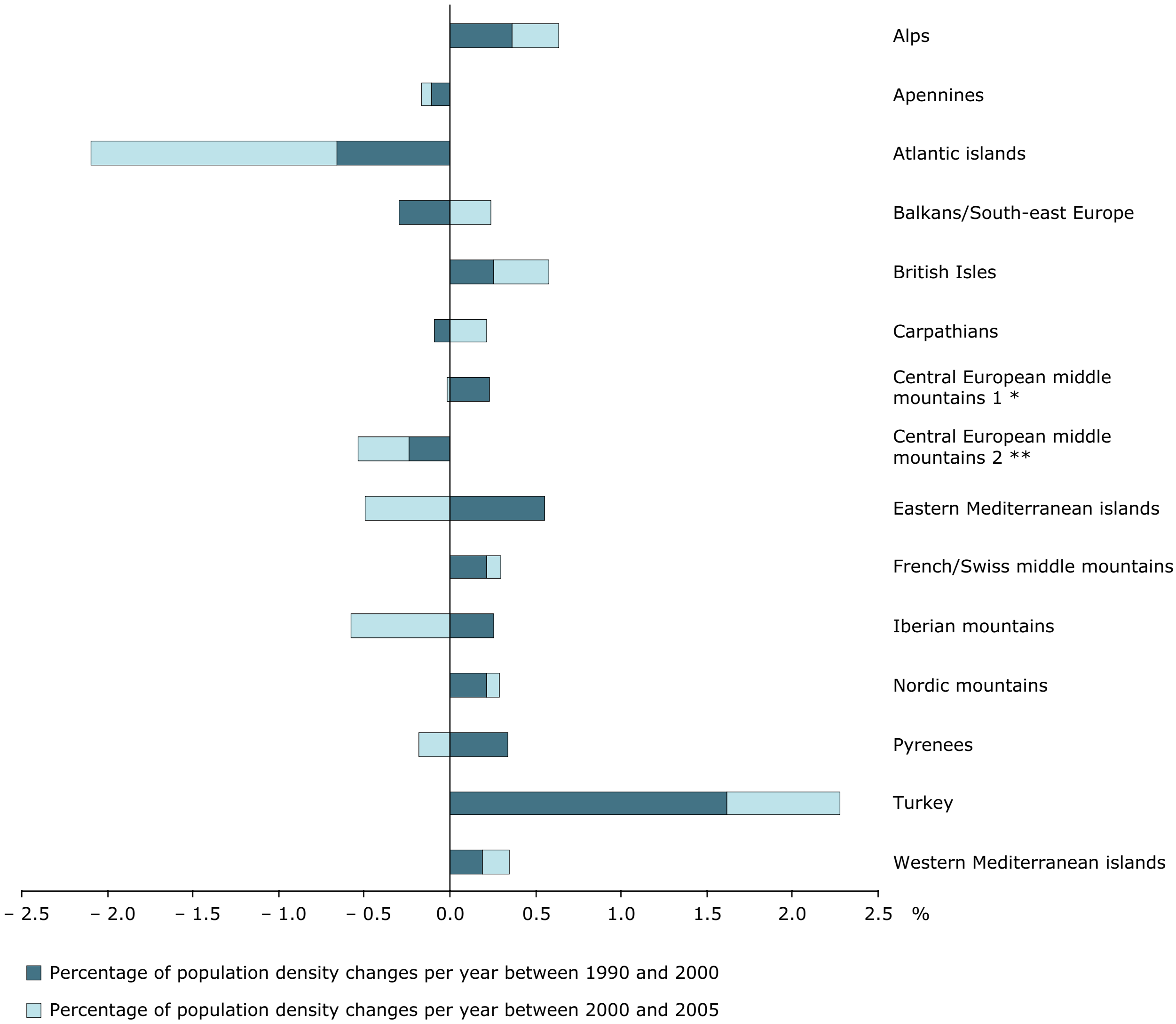
	1990–2000		2000–2005		1990–2005	
	Increase of inhab/km²	% of density increase	Increase of inhab/km²	% of density increase	Increase of inhab/km²	% of density increase
Alps	3.08	3.7 %	1.16	1.3 %	4.28	5.1 %
Apennines	– 1.23	– 1.0 %	– 0.37	– 0.3 %	– 1.59	– 1.4 %
Atlantic islands	– 21.90	– 6.6 %	– 22.14	– 7.2 %	– 44.10	– 13.3 %
Balkan/South-east Europe	– 2.29	– 3.0 %	0.90	1.2 %	– 1.37	– 1.8 %
British Isles	1.39	2.6 %	0.87	1.6 %	2.31	4.3 %
Carpathians	– 0.72	– 0.9 %	0.82	1.1 %	0.07	0.1 %
Central European middle mountains 1 *	4.72	2.3 %	– 0.15	– 0.1 %	4.66	2.3 %
Central European middle mountains 2 **	– 2.64	– 2.4 %	– 1.62	– 1.5 %	– 4.31	– 3.9 %
Eastern Mediterranean islands	2.31	5.6 %	– 1.10	– 2.5 %	1.26	3.0 %
French/Swiss middle mountains	1.91	2.2 %	0.37	0.4 %	2.36	2.7 %
Iberian mountains	1.16	2.5 %	– 1.35	– 2.9 %	– 0.17	– 0.4 %
Nordic mountains	0.13	2.1 %	0.02	0.4 %	0.16	2.6 %
Pyrenees	1.96	3.4 %	– 0.55	– 0.9 %	1.42	2.5 %
Turkey	10.09	16.2 %	2.39	3.3 %	12.55	20.1 %
Western Mediterranean islands	0.80	1.9 %	0.32	0.8 %	1.17	2.8 %
All massifs	4.5	7.2 %	2.1	3.1 %	6.6	10.6 %

Note: * = Belgium and Germany; ** = the Czech Republic, Austria and Germany.

Source: Gridded Population of the World Version 3 (GPWv3), CIESIN.

In contrast, in Switzerland, Poland, Serbia and Slovenia, the population density decreased outside the mountains and increased in the mountains. As both Switzerland and Poland have densities of over 100 inhabitants/km² in their mountains, these changes represent quite large population increases.

Figure 2.2 Annual population density change (%) per massif for the time periods 1990–2000 and 2000–2005



Note: * = Belgium and Germany; ** = the Czech Republic, Austria and Germany.

Source: Gridded Population of the World Version 3 (GPWv3), CIESIN.

Table 2.7 Population density change (%) per massif and per country between 1990 and 2005

Massif	Country	% 2005–1990
Alps	Austria	4.1 %
	Switzerland	1.7 %
	Germany	8.1 %
	France	13.8 %
	Hungary	– 3.5 %
	Italy	2.1 %
	Slovenia	0.5 %
Apennines	Italy	– 1.4 %
Atlantic islands	Portugal	– 13.4 %
Balkans/South-east Europe	Albania	– 12.1 %
	Bosnia	– 5.9 %
	Bulgaria	– 14.8 %
	Greece	0.9 %
	Croatia	11.0 %
	Hungary	– 7.9 %
	Montenegro	6.0 %
	Former Yugoslav Republic of Macedonia	7.9 %
	Romania	– 8.0 %
	Serbia	5.9 %
	Slovenia	1.3 %
British Isles	Ireland	12.8 %
	United Kingdom	3.7 %
Carpathians	Czech Republic	– 2.2 %
	Hungary	– 6.2 %
	Moldova	– 3.7 %
	Poland	4.4 %
	Romania	– 4.4 %
	Serbia	– 5.4 %
	Slovakia	11.8 %
	Ukraine	– 0.8 %
Central European middle mountains 1 (Belgium and Germany)	Belgium	10.6 %
	Germany	2.2 %
	Luxembourg	17.3 %
Central European middle mountains 2 (The Czech Republic, Austria and Germany)	Austria	3.8 %
	Czech Republic	– 0.8 %
	Germany	– 8.1 %
	Poland	– 6.3 %
Eastern Mediterranean islands	Cyprus	19.2 %
	Greece	0.4 %
French/Swiss middle mountains	Belgium	– 3.0 %
	Switzerland	2.8 %
	France	2.5 %
Iberian mountains	Spain	0.4 %
	Portugal	– 3.7 %
Nordic mountains	Finland	– 24.1 %
	Iceland	5.4 %
	Norway	3.8 %
	Sweden	– 14.6 %
Pyrenees	Spain	0.9 %
	France	1.8 %
Turkey	Turkey	19.2 %
Western Mediterranean islands	Spain	23.7 %
	France	7.5 %
	Italy	– 2.4 %
	Malta	11.6 %

Note: Increases are marked in white and decreases in blue.

Source: Gridded Population of the World Version 3 (GPWv3), CIESIN.

Table 2.8 Population density change (%) per country, within and outside mountain massifs, between 1990 and 2005

	Percentage of population density change between 1990-2005 within mountains	Percentage of population density change between 1990-2005 outside mountains
Austria	4.1 %	2.4 %
Belgium	10.3 %	3.4 %
Bulgaria	– 14.8 %	– 16.7 %
Croatia	11.1 %	11.1 %
Cyprus	19.3 %	19.9 %
Czech Republic	– 1.0 %	– 2.3 %
Finland	*– 24.0 %*	*3.3 %*
France	7.2 %	6.3 %
Germany	0.8 %	0.4 %
Greece	0.7 %	9.5 %
Hungary	– 6.3 %	– 5.0 %
Iceland	5.6 %	19.6 %
Ireland	12.7 %	16.9 %
Italy	*– 0.5 %*	*1.3 %*
Luxembourg	17.3 %	20.8 %
Former Yugoslav Republic of Macedonia	7.9 %	7.5 %
Malta	11.6 %	9.0 %
Moldova	– 3.2 %	– 2.0 %
Montenegro	6.0 %	5.5 %
Norway	3.7 %	11.2 %
Poland	*1.1 %*	*– 1.2 %*
Portugal	*– 4.5 %*	*0.9 %*
Romania	– 4.5 %	– 2.9 %
Serbia	*5.9 %*	*– 2.8 %*
Slovakia	11.8 %	7.4 %
Slovenia	*1.2 %*	*– 3.9 %*
Spain	0.7 %	3.6 %
Sweden	*– 14.5 %*	*0.2 %*
Switzerland	*2.5 %*	*– 2.0 %*
Turkey	20.1 %	37.9 %
Ukraine	– 0.8 %	– 8.3 %
United Kingdom	3.7 %	6.8 %
All Europe	10.6 %	7.5 %

Note: Contrasting trends are highlighted in italics, increases are marked in white and decreases in blue.

Source: Gridded Population of the World Version 3 (GPWv3), CIESIN.

3 Mountain economies and accessibility

3.1 Economic structures

There is a great diversity in economic structures across the mountains of Europe (Map 3.1), and many of these have been changing rapidly in recent years, especially in the new Member States (UNEP, 2007). The cultural identity and external image of many mountain areas remains tied to the primary sector (i.e. agriculture and forestry) and cultural landscapes are very important elements of the attractiveness of mountain areas for tourism. Today, the primary sector remains particularly important as a source of employment in southern and Eastern Europe, but is often experiencing significant internal change as the result of factors such as land reform and abandonment in areas further from settlements, and intensification nearer to settlements (see Chapter 7 and Box 3.1). However, the tertiary sector is the greatest source of employment in the mountains of all members of the EU-27 as well as Switzerland and Norway, except for the Czech Republic (European Commission, 2004) and Romania (UNEP, 2007). The public sector accounts for a particularly high proportion of this employment in the mountains of the Nordic countries and the French Alps (Borsdorf, 2008). A number of mountain areas have had relatively high employment in the secondary sector for decades or longer, usually due to the availability of specific geological and energy resources and also, historically, of labour in the form of agricultural workers in winter (Box 3.2).

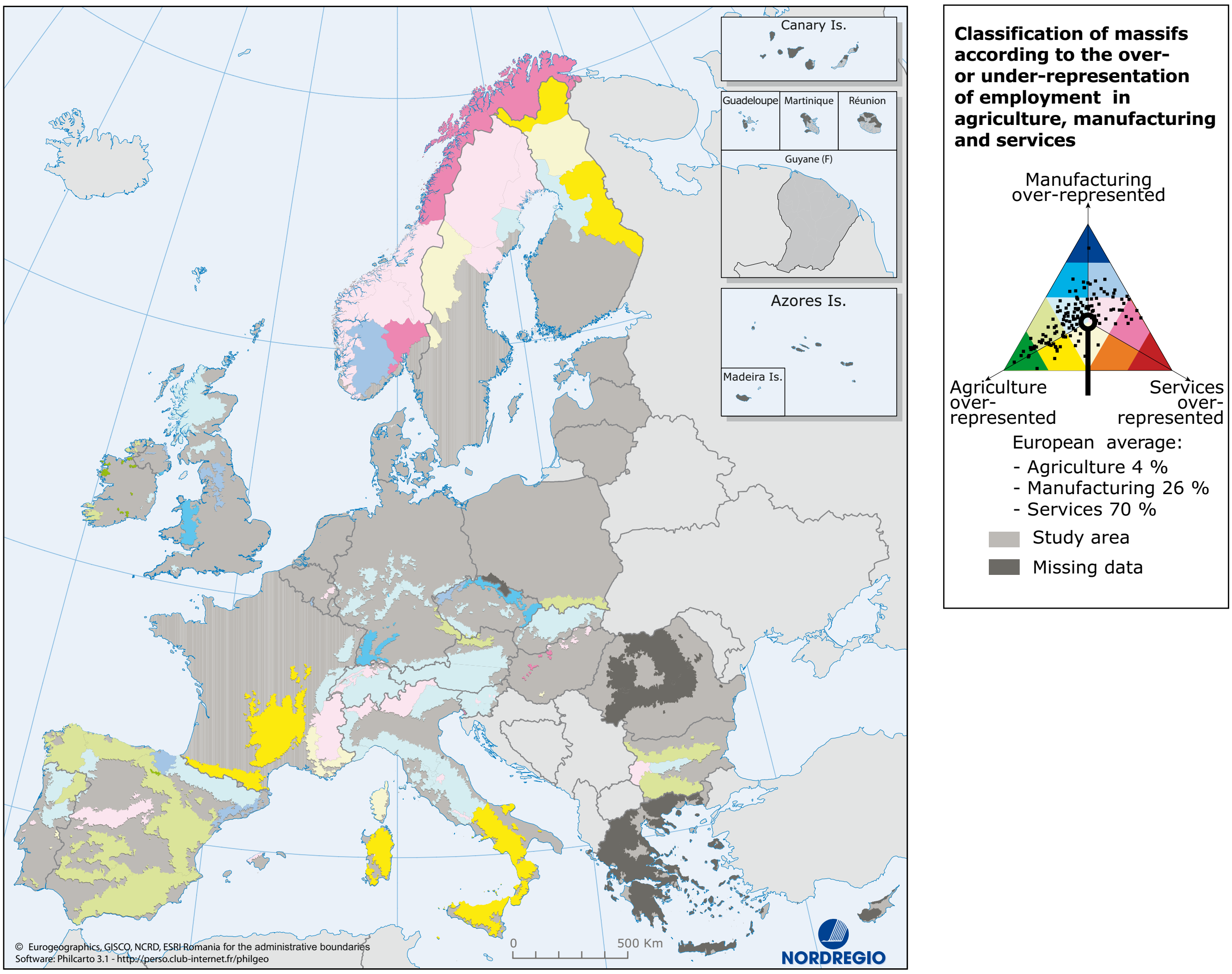
3.2 Economic density and accessibility

Previous work on the mountains of Europe, including all states that are now members of the EU, states of the former Yugoslavia, Albania, Moldova, Norway and Switzerland (Copus and Price 2002), has focused on the interactions between economic performance (in terms of GDP per capita) and peripherality (as defined by Schurmann and Talaat, 2000). This work used data at the NUTS 3 level and suggested that economic performance declined with increasing peripherality for NUTS 3 regions with at least 40 % of their area defined as mountainous, but that the impact of the presence of mountains 'is very entangled with that of peripherality, and can be improved by the presence of a large town or city' (Copus and Price, 2002: 33). The authors also concluded that 'NUTS 3 geography is clearly inadequate for such as exercise' (Copus and Price, 2002) because most NUTS 3 regions are large in area and have both mountain and lowland areas, usually with most of the population and economic activity in the latter. This conclusion has been borne out by subsequent analysis, for example for the Alps (Tappeiner *et al.*, 2008).

For the present report, economic performance is expressed in terms of economic density, defined as the income generated per square kilometre (EUR km^2). This can be considered as an integrative indicator of economic power and population density, which has been used to rank countries by their level of development (Gallup *et al.*, 1999). Economic density is defined in terms of GDP PPP (i.e. domestic product (GDP) at purchasing power parity (PPP) per capita, the value of all final goods and services produced within a nation in a given year divided by the average (or mid-year population for the same year) per capita, and is derived from CLC and EEA population density map. This work could only be done for the EU-27.

Accessibility through transportation and communication networks is a significant determinant of access of people to markets and other services. Accessibility is frequently used as a proxy for urban influence in rural areas; its converse is peripherality, as examined for Europe's mountain areas in European Commission (2004). A time-cost model was used, based on the cost-distance algorithms (ESRI 2006), to avoid interference with the economic density dataset and to use a comparable spatial unit and resolution. This approach calculates, for each square kilometre in Europe, the travel time to the nearest destination of interest given the transportation network. Since cities and towns of different sizes offer different opportunities and facilities, the travel time was calculated separately to towns and cities of more than 25 000, 60 000, 100 000, 250 000, 500 000 and 750 000 inhabitants. The final measure of accessibility is based on the average time-cost to these different

Map 3.1 Classification of massifs according to the over- or under-representation of economic sectors



Note: This map is from European Commission (2004), which addressed a different study area and defined massifs differently, especially in Sweden and Norway (see Section 1.2.4). Values estimated from data at NUTS 3 level for Czech Republic, Poland and Spain.

city sizes. As result of the inclusion of the larger cities within all the travel time maps, the weight of the larger agglomerations is larger than the small towns. Therefore the average travel time represents the relative importance of the different city sizes for the surrounding rural areas. Travel times are calculated based on a friction surface that includes different road types, railroads and frequently used ferry connections. Each road type was assigned an average travel speed derived from commonly observed speeds relative to road type. The network maps do not include minor roads and paths so an off-road speed is assumed that is slightly higher than would be realistic were no minor roads present. The off-road speed was decreased in regions with steep slopes. Again, these calculations were confined to the EU-27.

Table 3.1 shows the distribution of the economic density and accessibility for the various massifs and illustrates the high heterogeneity in economic density both within and between massifs. Economic density, in particular, probably derives mainly from differences in economic conditions between countries. The central European mountains in Belgium and Germany and the French/Swiss middle mountains have the highest average economic densities, whereas, the Carpathians and Balkans/South-east Europe have the lowest values.

In certain cases, high economic density results from the location of important urban conglomerations close to the mountain massif borders, when in the economic density raster, some pixels located in or

Box 3.1 The changing economic importance of pastoralism in the Causses, France

The Causses are high limestone plateaux at the western end of the French Massif Central. The steppe-like habitat is mainly a consequence of deforestation by the first people living there in the early Neolithic, 6 000 years ago. These were chiefly pastoralists keeping sheep, at a time when most people were hunters and gatherers, but goats and sheep had already been domesticated (Brisebarre, 1996). With the onset of a warmer climate 4000 years ago, livestock breeding became more important. Transhumance — the seasonal migration of herds between lowland areas to the mountains — from the lowlands of Languedoc to the Causses and the upper Cévennes also became a necessity because of the lack of pasture in the plains during summer.

Between the Middle Ages and the French revolution (16th to 18th centuries), much of the land and the buildings of the southerly Causse de Blandas belonged to two noble families. The rest of the land was owned by lesser noble families (Durand-Tullou, 1995). From the early 19th century, the land was bought by industrialists, bankers, lawyers and notaries. After 1850, farmers started to buy the land they had been farming, partly because the landowners had left the region and were no longer interested in these properties, partly because they had enough money to buy the land.

The now famous Roquefort cheese, legally protected since 1666, was the first to be given the Appellation d'Origine Contrôlée, in 1925. The pastoral economy on the Causse de Blandas was mainly dependent on the Roquefort cheese factories. The farmers delivered the sheep milk to a few collecting points, whence it was collected by lorry and taken to Roquefort. Industrialisation of cheese production started in the 20th century. The shepherds were expected to produce more and more efficiently. This required more modern sheep sheds and expensive infrastructure; many small shepherds could not afford these and ceased operation. In 1950, there were 80 farms, with resident full-time farmer son the 10 000 hectares of the Causse de Blandas: 75 % were smaller than 10 ha, 15% between 10 and 50 ha, and only 8 % larger than 50 ha. The discrepancy between the hard life on the Causse and perceived opportunities in the cities led to a dramatic exodus, which was accelerated because older farmers were not able or willing to adapt to more modern ways of farming. By the 1990s, only 20 farms remained. Today, the few remaining farmers who live on their farms each utilise several hundreds of hectares of land, having bought abandoned properties or parts of them (partly with EU subsidies) or by renting land, mainly from retired farmers. They can also, again partly thanks to EU aid, buy larger machines that allow them to do the work of the former shepherds in keeping the pastures free from encroachment by scrub and fertilising the soil mechanically.

Some farmers have started to diversify their businesses during the past two decades. New farmers arrived in the 'back to nature' movement and started to farm with partly new ideas and introduced cattle (of the Aubrac type, a tough animal from the Lozère), llamas, donkeys, and goats. Small producers now produce cattle meat, goat cheese and meat, and sheep cheese for sale in local markets, to shops in surrounding settlements and to restaurants. Others started bed and breakfasts, horse riding (on the estates or as tours of up to a week), donkey tours, or sell firewood. Thus, from being largely dependent on Roquefort, farmers have diversified considerably. This was probably the only way to maintain the local farming economy, and also helped to preserve pastoralism in a region that was originally shaped mainly by pastoralists.

Before humans came to the Causses, much of the land was forested. The very extensive pastoralism that has been going on for thousands of years has very slowly built the steppe like landscape we find now. The diversity of plants and animals is impressive, including species listed on the birds and habitats directives of the EU. Thus it can be said that the pastoralism on the Causses is a High Nature Value (HNV) farming system: see Section 7.4.2.

Source: Jean-Pierre Biber (European Forum on Nature Conservation and Pastoralism, France).

around cities present extremely GDP high values. Because of the broad boundaries of the massifs, some cities or pixels at the edge of cities are included within certain massifs. Thus, they are taken into account in the analysis and can distort the average, for example in the Alps around Milano and Torino and some cities in Germany. In other cases, cities are within the massif, e.g. Genoa is completely included in the Apennines (Map 3.2).

Maps 3.3 and 3.4 compare the economic density and accessibility of mountain and lowland areas.

Box 3.2 The transformation of the industrial sector in mountain areas

From the late 19th century, various industries based themselves in mountain areas due to the abundance of hydroelectric power and geological resources (minerals, coal etc.), as well as the availability of farm workers in winter. For instance, the Massif du Jura became, and remains, home to clock-making, the toy industry and spectacle manufacturing. The metal and chemical industries gravitated towards particularly advantageous alpine valleys. Other examples include textiles in the Vosges, paper manufacture in the Pyrenees, and timber in many mountain regions.

In the early 21st century, the industrial fabric of mountain areas is becoming increasingly fragile, because of their remoteness from development clusters, the diversification of energy sources and delocalisation to sites in the plains or with cheaper labour (Borsdorf, 2008). This has had repercussions on employment and local economies in the mountains. The progressive decline had, and still has, traumatic effects on local communities, but industrial employment has not disappeared from the mountains. In France, 30 % of employees in mountain areas work in industry. A total of 20 000 industrial firms, with over 27 000 jobs, are active in the parts of the Alps, Jura and Massif Central in the Rhône Alpes region. In this region, and elsewhere in Europe's mountains, mountain people have been forced to adapt to change and to find new foci for development. One solution has been to exploit the abundant snow, or 'white gold', through winter tourism, though climate change means that this may not be a reliable long-term strategy (Chapter 5). Traditional industries have also been gradually replaced by activities with a high added value such as microelectronics and nanotechnology, mechanics, plastic manufacturing, alpine equipment (ski lifts, winter sports and mountaineering equipment), and renewable energy. However, some firms and sectors remain fragile as they are subcontractors dependent on the dictates of major contractors and international competition.

The future would seem to lie in innovation through research, diversification and quality niche products 'made in the Mountains of Europe' but it is also crucial to integrate companies in an attractive local environment offering excellent services. Within the context of sustainable development, keys to success include a focus on all forms of innovation (technical, organisational, and human); banking on high-tech, quality products, protection of the environment, diversification, and networking (creating clusters or competitiveness centres); and territorial cooperation at different scales, including cross-border and trans-regional initiatives (Euromontana, 2008).

Mountain areas benefit from industrial experience combined with a wealth of know-how and competent resource and training centres; it is essential to use existing structures and respect the industrial heritage. This existing potential must be the starting point for the redevelopment and diversification of the activities of an area. For example, Styria in Austria, home to metallurgy, has left steel working and mineral mining behind to join a high-tech era while remaining true to its history and traditions. Similarly, companies working in the field of natural hazard management and specialist equipment manufacture have transferred their know-how and skills in acrobatic work to the construction industry. The highly specific assets of mountain areas, such as water and renewable energies, forest and timber provide potential openings for future development without disrupting the natural balance.

Source: Mission Montagne (Conseil régional Rhône-Alpes, France).

As can be seen in Map 3.3, the economic density in mountain massifs is generally low to medium, so the dominant colour goes from green (low) to yellow (medium) in the massifs. In the United Kingdom, the only parts with low economic density correspond clearly to the mountain areas. However, higher economic densities are observed in the central European and French/Swiss middle mountains. This can be partly explained by the location of part of the area in Switzerland, a country with a high economic density. Similarly, in the Apennines, the narrow shape of Italy results in a shorter distance between the mountains and the valleys where most cities are located. Indeed, the higher values are located at the edges of the massifs. This finding corresponds to the results presented in European Commission (2004) with respect to population densities: the highest densities are within 10 km of the edge of massifs.

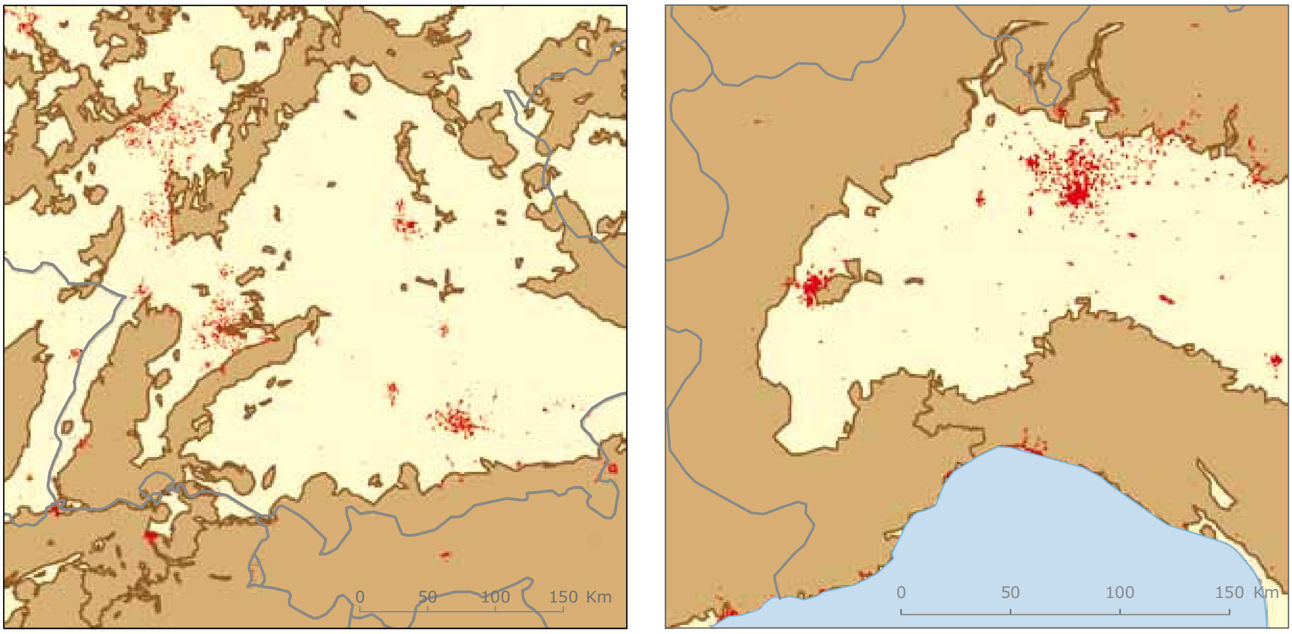
Most mountain areas are less accessible than lowland areas (Table 3.1, Map 3.4). The most accessible massifs are the Central European mountains and the French/Swiss middle mountains, and around the main cities of the other countries.

Table 3.1 Summary of economic density and accessibility indicators values per massif

Massif	Economic density (kEuro)		Accessibility (minutes)	
	Average	STD	Average	STD
Alps	2 083	10 216	146	35.3
Apennines	1 718	9 393	136	31.8
Atlantic islands	No data	No data	157	28.4
Balkans/South-east Europe	209	2 680	151	26.8
British Isles	580	5 436	155	34.4
Carpathians	203	1 412	148	23.7
Central European middle mountains 1 *	3 981	14 069	110	26.
Central European middle mountains 2 **	1 242	4 544	129	26.6
Eastern Mediterranean islands	469	2 080	169	15.3
French/Swiss middle mountains	2 565	9 655	132	39
Iberian mountains	524	6 542	156	26.6
Nordic mountains	388	3 642	178	9.8
Pyrenees	882	11 303	156	30.5
Western Mediterranean islands	515	3 353	155	21

Note: STD = standard deviation.
* = Belgium and Germany; ** = the Czech Republic, Austria and Germany.

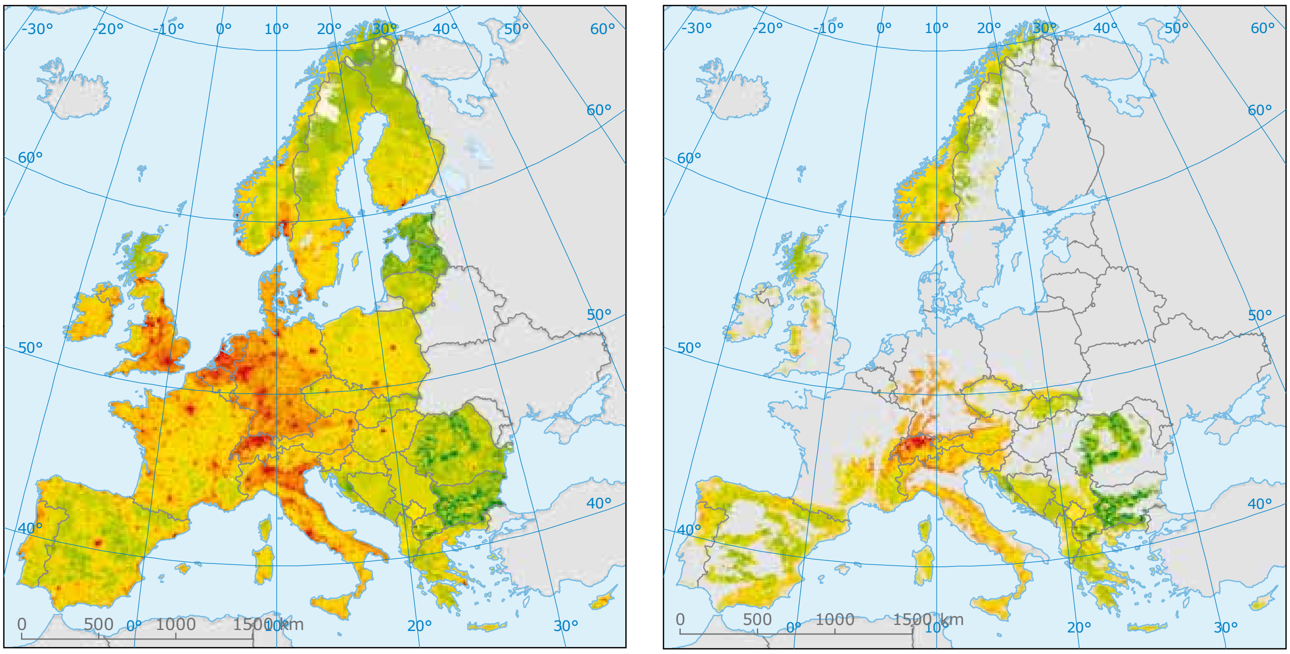
Map 3.2 Examples of areas with high GDP density values included in mountain massifs in Italy and Germany



Examples of areas with high GDP density values included in mountain massifs in Germany (left) and Italy (right)

- GDP density < 100 000 KEuro outside mountains
- GDP density < 100 000 KEuro inside mountains
- GDP density > 100 000 KEuro inside and outside mountains
- National boundary
- Massif boundary

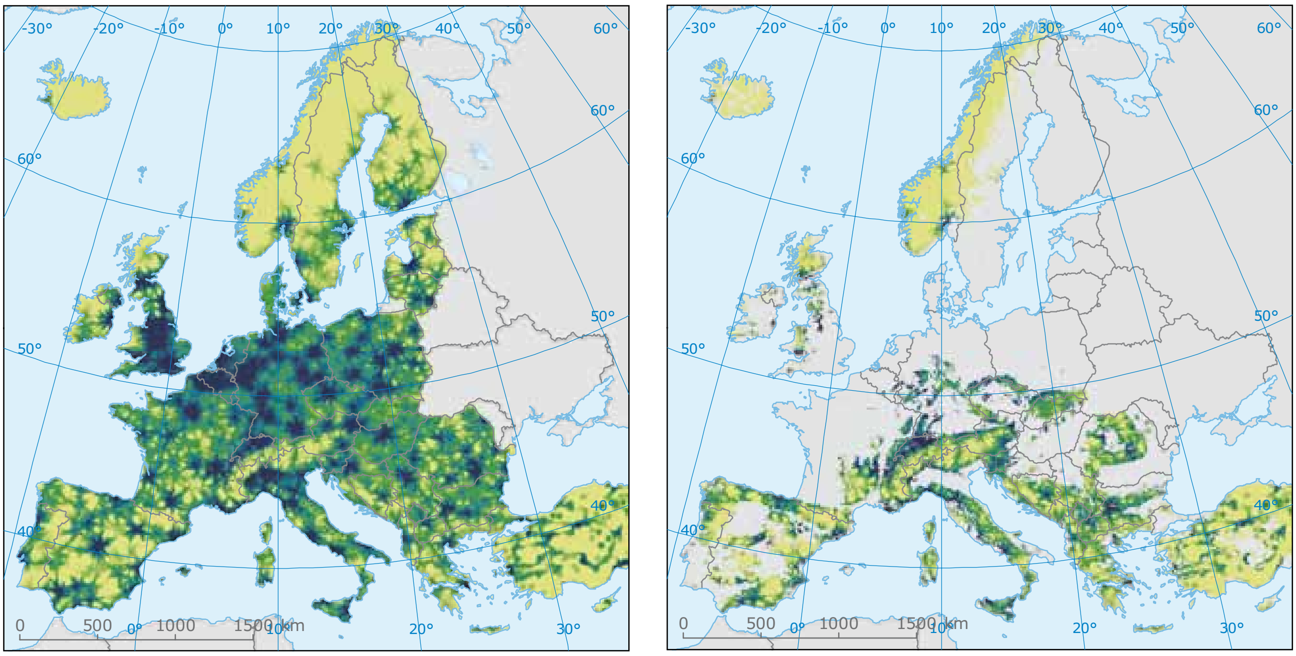
Map 3.3 Economic density in the EU-27 and in mountain areas



Economic density in Europe and in mountain areas

Economic density (KEuro) 3 213 790 – 0

Map 3.4 Accessibility in the EU-27 and in mountain areas



Accessibility in Europe and in mountain areas

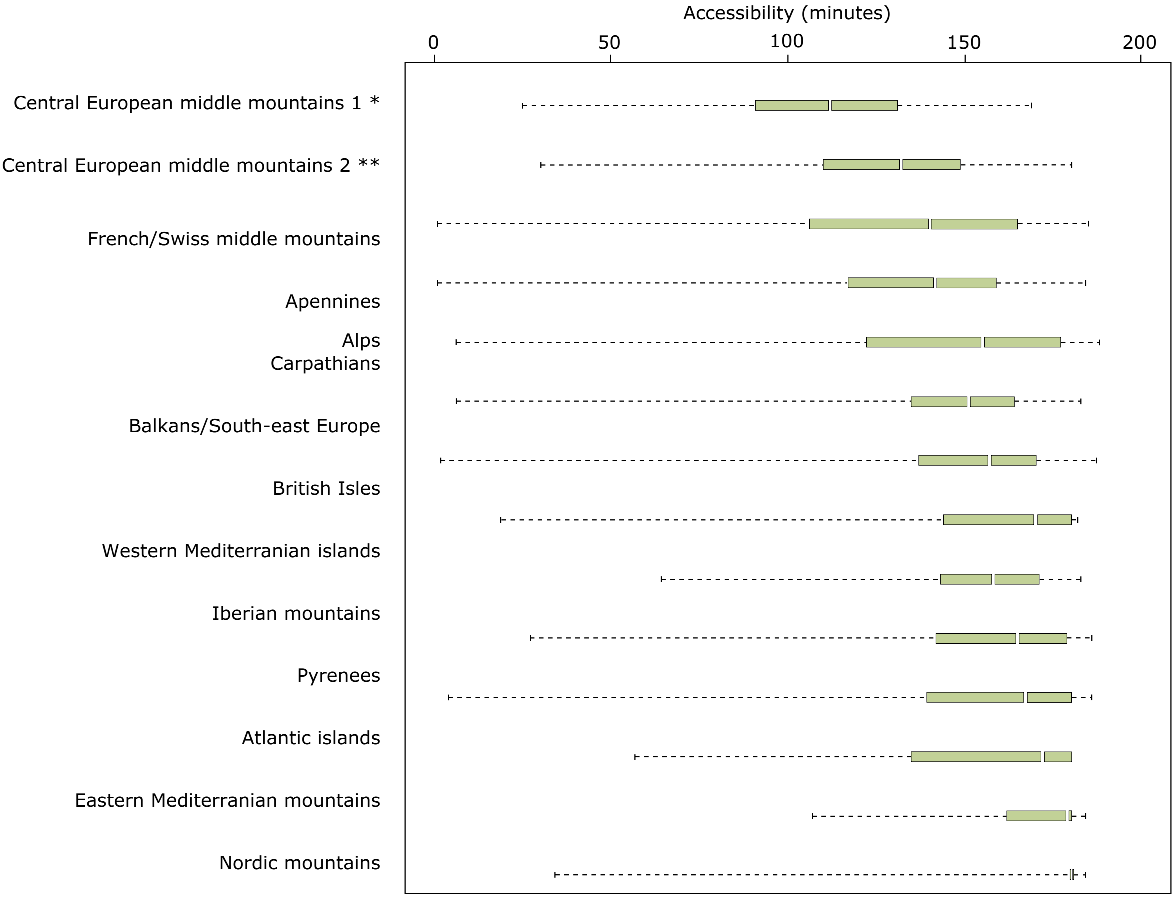
Accessibility (minutes) 190 – 0

Figure 3.1, in which the massifs are sorted from the most to the least accessible, also shows how the variability of accessibility varies between massifs. For example, while the British Isles and western Mediterranean islands have the same average accessibility, there is a much greater variation in accessibility (difference between 25th and 75th percentiles) and there are as greater number of less accessible areas in the British Isles, which is not surprising given their greater spatial extent. A similar comparison can be made for the Alps and the Carpathians: the Carpathians massif is more accessible, as it contains proportionally fewer remote areas. Further detail on the Alps is provided in Box 3.3.

As noted above, the results shown in Maps 3.3 and 3.4 are linked to the geographical characteristics of the massif. In Italy and Germany, the mountain areas are never far from big cities, thus they are more accessible. In Switzerland, almost the entire country is considered as part of a mountain massif. The northern part of the country is the most populated and most accessible mountain area in Europe. The least accessible mountains are the Nordic mountains.

Overall, a comparison of Maps 3.3 and 3.4 shows that accessibility is less heterogeneous than is economic density in mountain areas, indicating that low accessibility is a common feature of them. However, the broad areas selected for the delineation of some of the massifs leads to the inclusion of some high valleys, e.g. in Switzerland or Italy which do not present the same characteristics, thus introducing some bias to the results. Copus and Price (2002) and European Commission (2004b) also came to similar conclusions, which also correspond with the statement in the Fourth Cohesion Report that mountain areas are 'extremely diverse in terms of socio economic trends and economic performance' (European Commission, 2007).

Figure 3.1 Box plots representing the accessibility in minutes per massif



Note: * = Belgium and Germany; ** = the Czech Republic, Austria and Germany.
The green bars show values between the 25th and 75th percentiles. The white space in the green bars is the median (not the mean as shown in Table 3.1).

Box 3.3 Transport and accessibility in the Alpine region

The Alps differ from other European mountain ranges by being situated between some of Europe's most productive industrial countries. They contain areas with strong economies, high population densities, and high intensities of tourism. These are pre-conditions for high levels of passenger and freight transport as well as commuting. Consequently, and as a result of EU market integration, transport volumes have risen continuously in recent decades and many Alpine citizens feel harmed, particularly by road transport, and perceive any further extension of transport as a disadvantage rather than as an increase of accessibility.

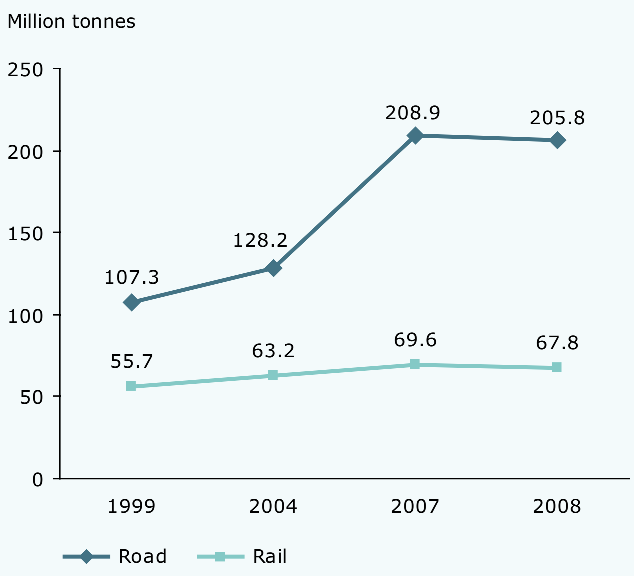
Transport
Road and rail are the dominant modes of transport for both passengers and freight. After freight transport by road nearly doubled over the previous decade (BAV, UVEK 2008), there was stagnation in 2008 in both road and rail freight transport. In general, road freight transport has increased to a significantly greater degree than rail freight transport (Figure 3.2), now accounting for about 75 % of the freight crossing the Alps, and dominating in most countries: e.g. 86 % road, 14 % rail in France; 69 % road, 31 % rail in Austria. The relationship is the opposite in Switzerland, which has a different transport policy: 36 % road, 64 % rail (Cross Alpine Freight Transport survey, 2004; Survey in Alpine Convention 2007).

The Transport Protocol of the Alpine Convention (AC) defines two categories of transport:

- Intra-Alpine transport, whose origin and destination lies within the Alpine space, or transport whose destination or origin lies within the Alpine space;
- Trans-Alpine transport, whose origin and destination lies outside the Alpine space.

It appears likely that the exchange of goods between North and South and linkages between central European countries and Mediterranean ports mean that trans-Alpine transport is significant. However, clear analyses are not easy, as origin and destination data of counted trucks are aggregated at administrative units (NUTS 2) which are broader than the AC area. Origin and destination data of the Cross Alpine Freight Transport (CAFT) surveys suggest that, of all Alpine crossing road transport movements, about 19% neither originate nor end in a region that are at least partly within the AC area. About 33 % of transport movements take place between regions that are at least partly within the AC perimeter, and about 47 % are between partly AC regions and non-AC regions (Alpine Convention, 2007).

Figure 3.2 Alpine-crossing transport total volumes 1999–2008 for the Alpine Arc C (Alpine crossings from Ventimiglia in the west to Wechsel in the east)

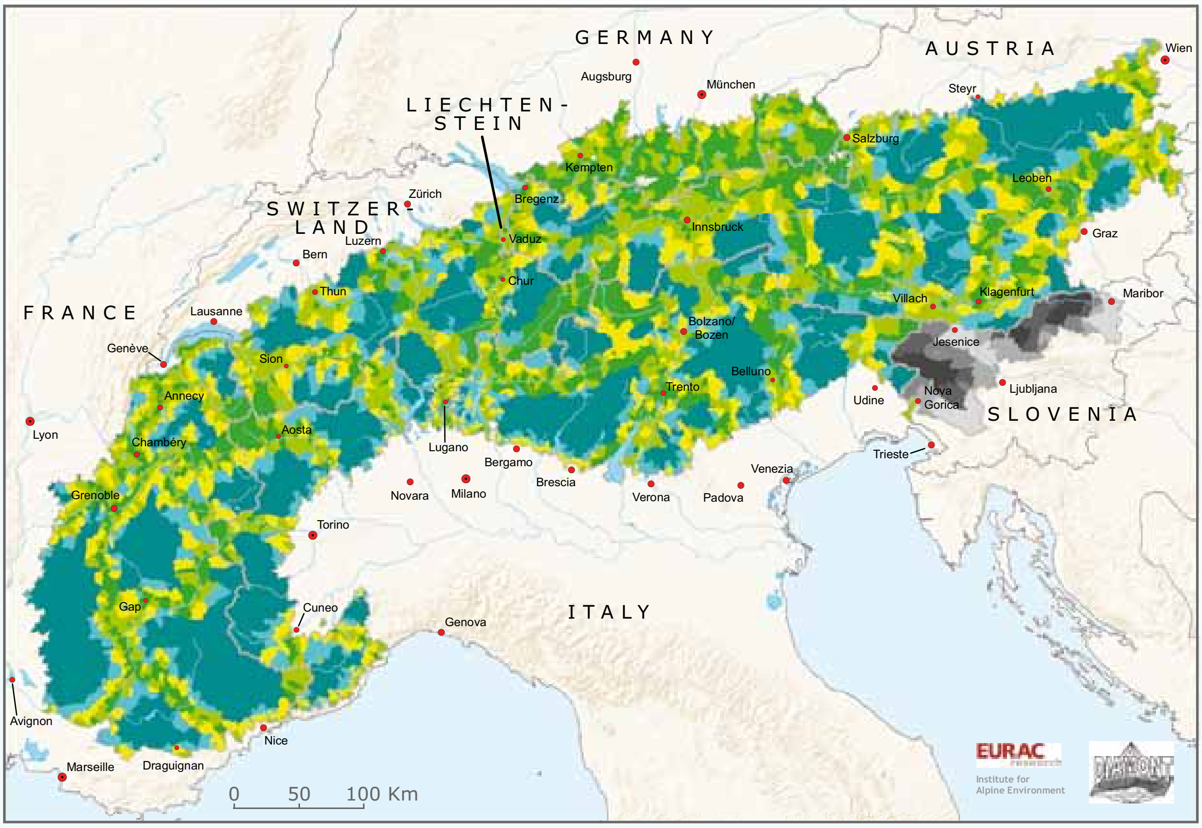


Source: Alpinfo, 2008.

Accessibility
Although the Alps may be perceived intuitively as a region of low accessibility in terms of transport, in reality the accessibility of the region by road and rail differs remarkably, between high accessibility at the fringes of the mountain ranges (particularly in the catchment areas of large agglomerations) and the main valleys, and lower accessibility in the centre of mountain ranges (Alpine Convention 2007). An analysis of road accessibility indicates that about 58 % of all Alpine municipalities are less than 14 km away from the next major road or motorway, while about 28 % are at a distance greater than 20 km (Tappeiner *et al.*, 2008: Map 3.5).

Box 3.3 Transport and accessibility in the Alpine region (cont.)

Map 3.5 Road distance to nearest motorway or major road on base of LAU2-units (municipalities)



Road distance to nearest motorway or major road

Road distance (km)

≤ 5	> 5–15	> 15–25	> 25–35	> 35
≤ 2	> 2–8	> 8–14	> 14–20	> 20

Source: Tappeiner *et al.*, 2008.

Accessibility in the Alps in 1995 was calculated at 3.67 million people within three hours travelling time (Pfefferkorn *et al.*, 2005, in CIPRA 2007). Assuming that the planned large railway tunnel projects are completed by 2020, accessibility will rise to an average of 9 million people within three hours, corresponding to the highest values in 1995. Even the most remote municipalities will reach the average values of 1995.

Options for future transport development

In the long term, a transformation of the transport system will be needed to achieve the transport objectives of the Alpine Convention (i.e. polluter-pays principle, modal shift) and to comply with the objectives of sustainable development. General principles which may contribute to a comprehensive bundle of measures include:

Box 3.3 Transport and accessibility in the Alpine region (cont.)

- strategic measures, such as stronger integration of transport issues into spatial policies;
- regulatory measures, such as a system of ecopoints for limiting heavy goods vehicles transiting through Austria, as proposed by Tirol; or speed limits, as on the Inntal-motorway, which depend on the real-time emissions along the motorway;
- infrastructure measures, such as the large EU projects (Lyon-Torino, Brenner base tunnel) and projects of the Swiss NEAT (St. Gotthard, Lötschberg base tunnel) currently under construction or realised to improve transalpine railway connections;
- economic measures, such as internalisation of external transport costs for end consumers, to foster changes in mobility behaviour and market choices. One recent approach is the Alpine Crossing Exchange which aims to transfer transalpine freight transport from road to rail by issuing tradable transit rights for road freight traffic.

Source: Stefan Marzelli (Ifuplan, Germany).

Similar conclusions can be drawn from Table 3.2, which shows national averages (and standard deviations) of economic density and accessibility. Standard deviations are very high for economic density, particularly in view of the extreme values of some pixels quoted previously, so no conclusion can be drawn. Standard deviations of accessibility are much lower (see also Figure 3.3) and it is, therefore, appropriate to compare averages inside and outside mountains, even though these may not be statistically significant. Again, there is a clear general trend in that average accessibility is either

Figure 3.3 Mean and standard deviation of accessibility within and outside mountains per country

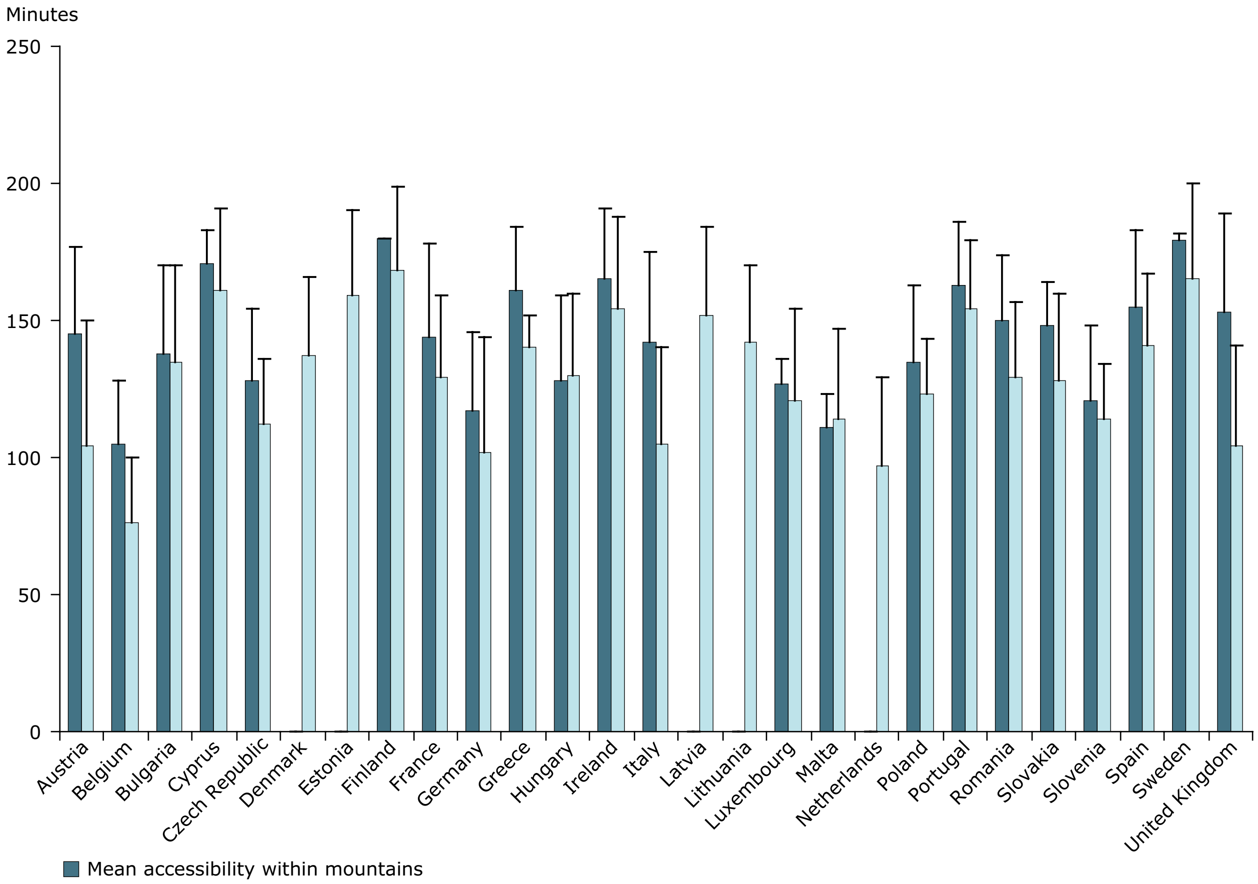


Table 3.2 Summary of average values and standard deviations (STD) for economic density and accessibility indicators per country

Country	Economic density (KEuro)				Accessibility (minutes)			
	Inside mountains		Outside mountains		Inside mountains		Outside mountains	
	Average	STD	Average	STD	Average	STD	Average	STD
Austria	1 655	8 707	5 148	34 362	145	32	104	37
Belgium	909	2 767	8 785	37 522	105	23	76	35
Bulgaria	119	1 270	159	1 402	138	32	135	26
Cyprus	412	923	2 003	4 522	171	12	161	20
Czech Republic	516	2 147	1 022	5 506	128	26	112	32
Denmark	No mountain		4 092	23 798	No mountain		137	28
Estonia	No mountain		161	2089	No mountain		159	25
Finland	8	27	417	4 516	180	0	168	20
France	1 083	7 046	3 155	34 497	144	34	129	32
Germany	3 614	12 647	6 323	23 190	117	29	102	33
Greece	394	4 436	2 612	21 906	161	23	140	33
Hungary	651	4 733	649	5 962	128	31	130	28
Ireland	374	4 039	1 845	13 327	165	26	154	32
Italy	1 795	9 848	7 622	29 882	142	33	105	35
Latvia	No mountain		149	2 276	No mountain		152	34
Lithuania	No mountain		208	1472	No mountain		142	30
Luxembourg	5 692	16 294	8 840	30 390	127	9	121	12
Malta	3 135	8 204	14 917	28 059	111	12	114	42
Netherlands	No mountain		12 611	32 999	No mountain		97	30
Poland	502	2 010	690	5407	135	28	123	31
Portugal	687	3 545	1 814	13 155	163	23	154	31
Romania	102	784	236	2 321	150	24	129	29
Slovakia	275	1 438	811	4 159	148	16	128	24
Slovenia	780	2 871	1 949	6 755	121	27	114	30
Spain	578	8 014	2 123	21 647	155	28	141	35
Sweden	30	260	668	6 648	179	3	165	24
United Kingdom	614	5 637	8 562	39 900	153	36	104	46

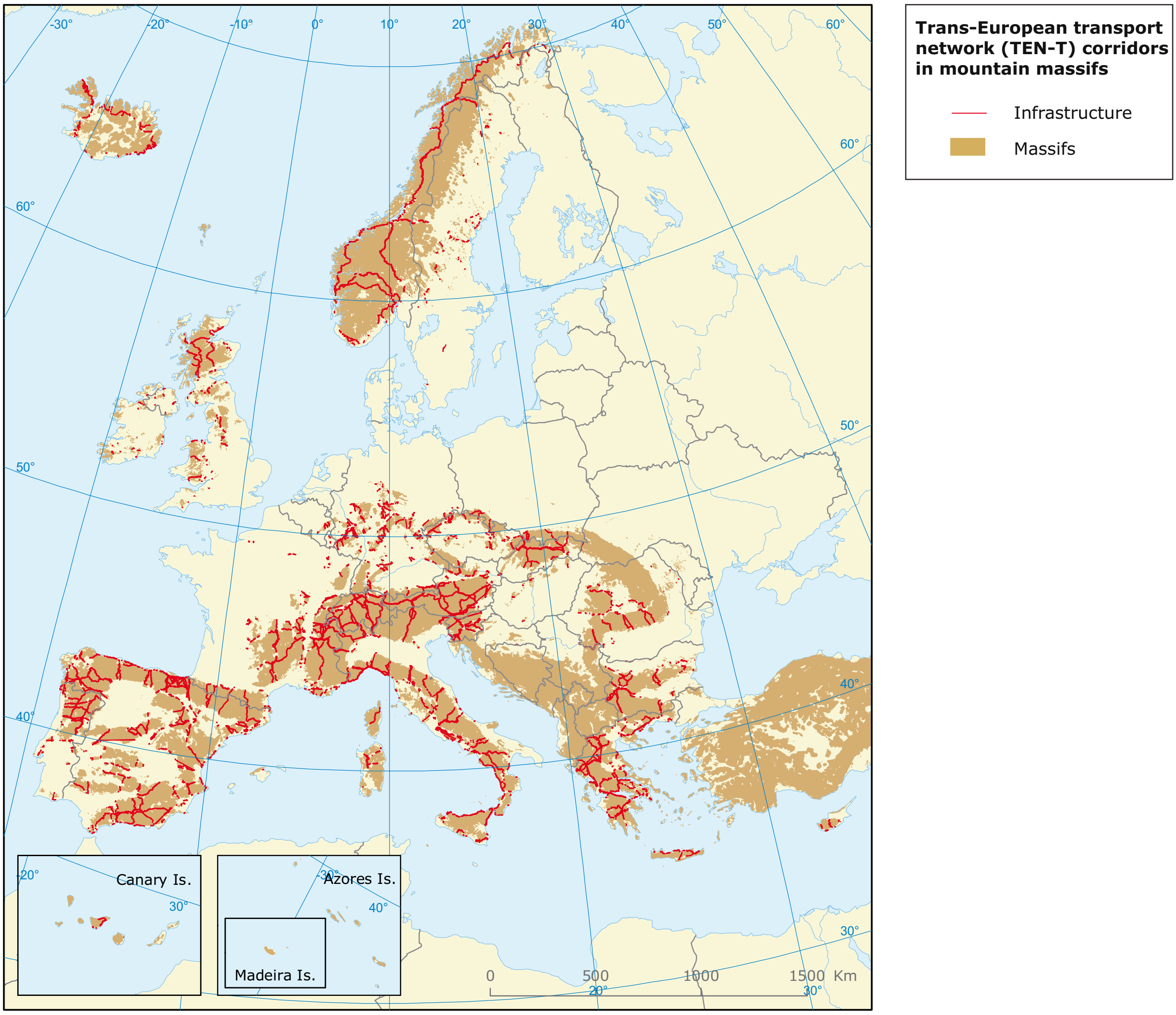
lower or similar within mountains than outside mountains. Countries where the difference is most marked include Austria, Belgium, Greece, Italy and, particularly, the United Kingdom. Countries where the difference is least include Bulgaria, Hungary, Portugal, and Slovenia. Considering countries with a significant mountain area, the most accessible mountains are in Germany, Slovenia, the Czech Republic, and Bulgaria; and those with the least accessible mountains are Sweden, Cyprus, Ireland, Portugal, and Greece. There is no clear geographical or historical pattern to accessibility.

3.2.1 TEN-T corridors

Mountain areas have very often been regarded as barriers to communication for those who live in adjacent lowland areas. According to national priorities, and frequently for military or strategic reasons, particularly in the states along the former 'Iron Curtain', road and rail access was developed from the lowlands into mountainous border areas, but not across borders. With the expansion of the European Union, European policy makers have decided to establish a single, multimodal network integrating land, sea and air transport networks. The aim of the Trans-European transport network (TEN-T) is to allow goods and people to circulate quickly and easily between Member States and to assure international connections, and is a key element in the Lisbon strategy for competitiveness and employment in Europe (http://ec.europa.eu/transport/infrastructure/index_en.htm). While the development of the TEN-T clearly contributes to economic and social cohesion at the European scale, it also creates disparities in accessibility within mountain regions and, like all types of transport infrastructure, may be linked to environmental impacts such as noise, pollution, and fragmentation of habitat and ecological connectivity. A number of studies have been done to evaluate these impacts in the mountains of the EU-27.

A significant number of TEN-T corridors cross mountain massifs (Map 3.6). This infrastructure covers a very small proportion of the area of a massif: greater than 1 % only in the Central European middle mountains (1.3 %). However, the environmental impacts of this infrastructure extends well beyond its physical limits and the proportion of each massif directly affected by this infrastructure varies considerably, as shown in Figure 3.4, which uses data from the GISCO database, 'Transport v1 (2005) TEN Links', which records the location of roads, railways and ferries. The database includes no relevant data for Albania, Andorra, Bosnia and Herzegovina, and Kosovo under UNSCR 1244/99, the former Yugoslav Republic of Macedonia, Montenegro, or Turkey. The percentage of mountain area affected by infrastructure is based on analysis of the 1 km buffers around the infrastructure recorded in this database. Massifs whose area is most influenced are either in or adjacent to highly-populated areas: the Central European middle mountains 1, the Alps, and the French/Swiss middle mountains. The proportion is considerably higher in Central European middle mountains 1 than 2, probably reflecting the two regions' different histories, with investment in the latter being more recent, since the expansion of the EU. The Pyrenees and the Apennines also have relatively high proportions. The relative extent is low in the Balkans/South-east Europe (where some countries are not included) and the Carpathians, which include countries that have only recently joined the EU, or have yet to join, as well as in the sparsely-populated mountains of the British Isles and the Nordic countries. The low values for the various islands reflect their distance from major

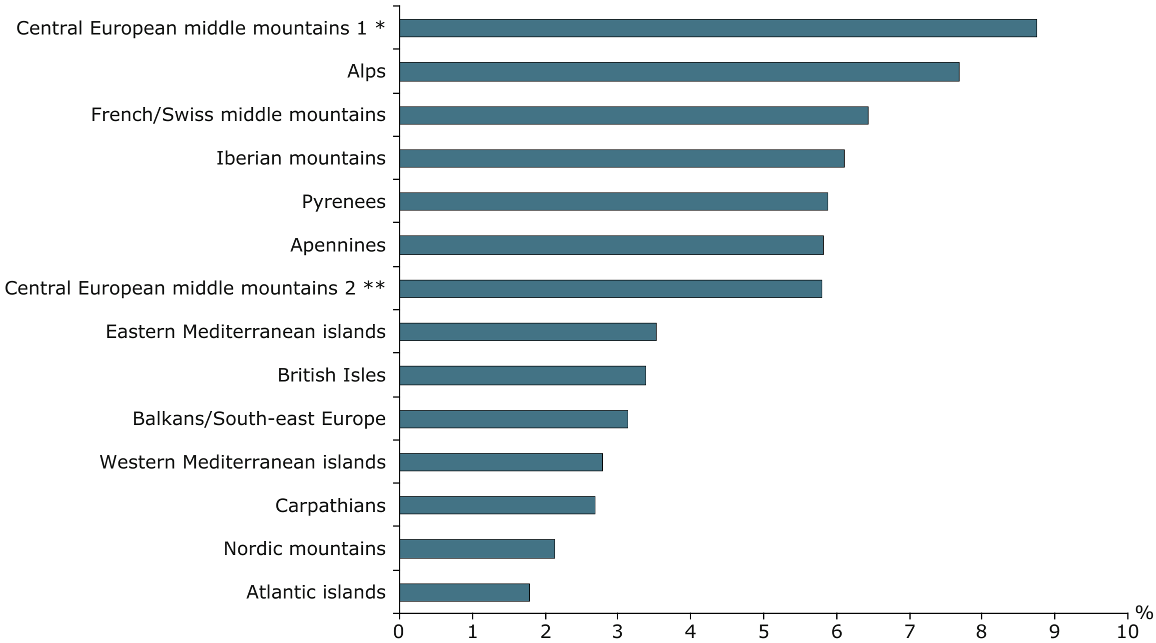
Map 3.6 Location of TEN-T corridors crossing mountain massifs



transport networks and major centres of population and industry.

From these data, it was possible to calculate the proportion of the mountain population influenced by TEN-T infrastructure. Impacts may be positive (e.g. increased access to services, opportunities for commuting) and negative (e.g. noise (Box 3.4), pollution). The relative importance of these impacts changes with distance from the infrastructure. Accordingly, analyses were made of the proportion of population living within one, five and ten km of the infrastructure for both massifs and countries (Table 3.3). This approach gives rather different results to those presented in Table 3.1, which presents accessibility based on the average time-cost

Figure 3.4 Proportion of mountain massifs affected by TEN-T infrastructure



Note: * = Belgium and Germany; ** = the Czech Republic, Austria and Germany.

Table 3.3 Percentage of population near to TEN-T corridors within mountain massifs

Mountain Massif	TEN-t 1 km	TEN-t 5 km	TEN-t 10 km
Alps	36.9	61.8	74.7
Apennines	24.8	52.5	65.1
Atlantic islands	24.7	55.0	61.0
Balkans/South-east Europe	10.7	23.0	28.6
British Isles	17.8	42.2	70.3
Carpathians	16.8	33.4	44.2
Central European middle mountains 1 *	21.0	49.8	69.7
Central European middle mountains 2 **	19.4	44.1	66.0
Eastern Mediterranean islands	13.0	29.2	40.9
French/Swiss middle mountains	33.6	61.2	77.2
Iberian mountains	30.3	57.7	74.4
Nordic mountains	27.6	52.4	59.9
Pyrenees	30.1	62.2	78.8
Western Mediterranean islands	13.8	29.1	42.1

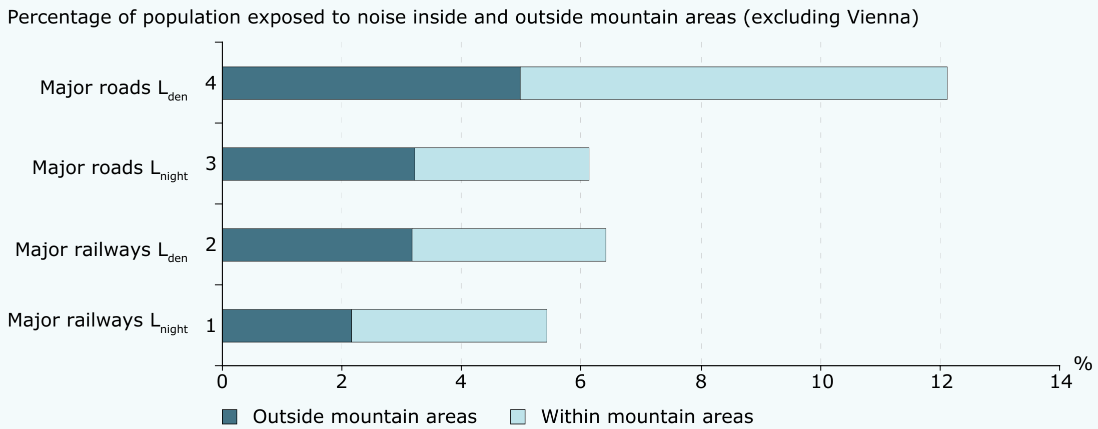
Note: * = Belgium and Germany; ** = the Czech Republic, Austria and Germany.

Box 3.4 Noise in the mountains of Austria

One of the principal impacts of transport infrastructure on human populations — as well as on wildlife — is that of noise along transport corridors. The relationship between environmental noise and public health has emerged as a key issue in environmental legislation and policy, as exposure to high levels of noise, particularly for long periods of time and at night causes detrimental health effects. In 2002, the European Commission introduced the Environmental Noise Directive (END: Directive 2002/49 EC relating to the assessment and management of environmental noise). Although this is a step forward in improving knowledge of the situation of noise, limitations remain due to data comparability, delays and inconsistencies with reporting.

To evaluate differences in noise exposure within and outside mountain areas, the example of Austria has been used, as the necessary data are available. Noise contour maps of major roads and of major railways have been used to estimate the potential population exposed to certain levels of noise inside and outside mountain areas, using two main indicators, L_{den} (day, evening and night) and L_{night} for roads with more than 6 million vehicles per year and railways with more than 60 000 train passages per year (Figure 3.5). Population data were derived from a population density grid developed by the Joint Research Centre and scaled by the total number of reported people, excluding agglomerations. About 458 000 people (5.7 % of the national population) are potentially exposed to a long-term average level above 55 dB Lden due to road traffic inside mountain areas. The impact of railways is less pronounced, with about 208 000 people exposed to the same long-term average level. However, at night, 188 000 people are potentially exposed to levels above above 50 dB Lnight inside mountain areas due to road traffic, while 209 000 people are exposed to railway noise.

Figure 3.5 Percentage of population exposed to noise within and outside mountain areas in Austria due to major roads and major railways with more than 6 mio vehicles or 60 000 train passages per year (excluding Vienna)



Just under half of Austria's population lives in mountain areas in Austria; yet the proportion of people exposed in mountain areas is higher than outside mountain areas. However, other roads not considered in the END may still have a significant impact, which could imply that more people are exposed to damaging levels of transport noise. However, for primary prevention of adverse health effects, the World Health Organization (2009) recommends that people should not be exposed to night noise levels greater than 40 dB of L_{night},outside. This would imply that many more people may be exposed to possibly damaging levels of night time noise than can be currently assessed by the present END reporting requirements.

Further development of an effective policy on noise for Europe, as well as full and effective implementation of noise action plans, particularly at night, should be aimed to reduce the scale of exposure to high noise levels and protect areas where the noise quality is found to be good. In addition, further research and effective policy are essential to ensure that the impact of noise on wildlife is not adversely affected by the same sources that affect people.

Source: Núria Blanes, Jaume Fons, Alejandro Simón and Juan Arévalo, ETCLUSI — UAB (European Topic Centre on Land Use and Spatial Information, Universitat Autònoma de Barcelona).

to different city sizes. Table 3.3 shows that the proportions of population closest to these transport corridors are highest in the Alps, French/Swiss middle mountains, Iberian mountains and Pyrenees. However the rank order varies with distance, reflecting different population densities: the greatest proportion of the population in the Alps is within 1 km; the greatest proportion of the population in the Pyrenees is within 5 km and 10 km. The importance of population density is shown particularly for the Nordic mountains: where the rank decreases markedly from 1 km (5th) to 5 km (7th) to 10 km (10th). For these five massifs, as well as the Apennines and the Atlantic islands, at least half of the population lives within 5 km of the corridors. For the British Isles and Central European middle mountains 1 and 2, at least half of the population lives within 10 km. However, less than half of the population lives within 10 km of the corridors in the eastern and western Mediterranean islands and the Carpathians. In the eastern and western Mediterranean islands this presumably because of the sparseness of the population and, for the Carpathians, at least partly because of the limited infrastructure. The proportions for the Balkans/South-east Europe massif are always the lowest, which may not accurately reflect the density of infrastructure and its relation to population because data were not available for five countries in this region.

4 Ecosystem services from Europe's mountains

Ecosystem services (ES) are the 'benefits that humans recognise as obtained from ecosystems that support, directly or indirectly, their survival and quality of life' (Harrington *et al.*, in press, expanded from MA, 2003) and mountain ecosystems provide a multitude of these essential services to humankind across Europe and globally. The Millennium Ecosystem Assessment (MA), the most comprehensive global examination of the state of the world's ecosystems and the services they provide, defined four major categories of services: provisioning, regulating and cultural services that directly benefit people, and the supporting services needed to maintain the direct services (MA 2005a). **Provisioning** services are products obtained from ecosystems (e.g. food, water, timber), regulating services are benefits obtained from regulation of ecosystem processes (e.g. water purification, pollination), **cultural** services are non-material benefits obtained from ecosystems (e.g. recreation, aesthetic experiences) and **supporting** services are services necessary for the provision of all other ecosystem services (e.g. soil formation, nutrient cycling). However, while the first three of these categories are uncontroversial and generally accepted, there is considerable controversy over the validity and usefulness of supporting services. The uncertainties come from two directions. First, there is no simple dividing line between what constitutes regulating and supporting services, so some workers prefer to pool these together. Second, the opinion of many ecologists is that supporting services are not services at all, but ecosystem processes and properties which are an integral part of ecosystem functions that happen independently of human benefit or valuation. This chapter follows the most updated service classification provided by the MA (Carpenter *et al.*, 2009) for provisioning, regulating and cultural services, without referring to ecosystem processes as supporting services. It is based particularly on the most recent appraisal of the status and trends of ecosystem services in Europe as documented by the RUBICODE project (www.rubicode.net), funded by the European Commission as a 6th Framework Coordination Action Project, and by the scientific publications resulting from that project.

Chapter 24 of the MA (Körner *et al.*, 2005) assessed the conditions and trends associated with mountain biota and their ecosystem services at the global scale, treating regulating and supporting services together. The authors of this chapter highlight the exceptionally high multifunctionality of mountains (see also Messerli and Ives, 1997). Thus mountains provide a disproportionately large number of ecosystem services to many human communities. A key issue here is that the service beneficiaries — the humans affected positively by the provision of a particular service (see Harrington *et al.*, in press) — include not only the local residents of the mountains, but also people inhabiting the lowlands. Mountain ecosystems can only continue to provide all these services in a rapidly changing world if such multifunctionality is taken into account in their management. However, to manage for multiple ecosystem services we must first identify, quantify and value the full suite of services provided by mountains. The remainder of this chapter is an account of the present state of the art.

The wide spectrum of mountain ecosystem services arises from a diverse range of 'ecosystem providers' within mountain ecosystems. Ecosystem service providers (ESPs) are the component populations, communities, functional groups of organisms, interaction networks or habitat types that provide ecosystem services (Luck *et al.*, 2009, adapted from Kremen, 2005). The ESP approach is paralleled by a similar concept, that of the service providing unit (SPU): the collection of individuals of a given species and their characteristics necessary to deliver an ecosystem service at the desired level (Luck *et al.*, 2009, adapted from Luck *et al.*, 2003). This also allows for negative influences and the necessity for trade-offs within ecosystems by recognising the concept of the ecosystem service antagoniser: an organism, species, functional group, population, community, or trait attributes thereof, which disrupts the provision of ecosystem services and the functional relationships between them and ESPs (Harrington *et al.*, in press). Although originally developed independently, these two approaches have now been brought together, so that ESP and SPU should represent a continuum of service providers across various organisational levels. The advantages of this are two-fold, both linking the appropriate organisational levels for a given service or group of services and accentuating the need to quantify the provider characteristics required to deliver an ecosystem service in the light of beneficiary demand and ecosystem dynamics (Luck *et al.*, 2009).

Consideration of the provision of ecosystem services at levels to satisfy beneficiary demand infers that some sort of value must be placed on each service (Box 4.1). Quantification is necessary to determine the relative importance of the services to those that benefit. It also exposes situations of conflicting interest and trade-offs in service provision and demand by different stakeholders. Thus, valuation of ecosystem services aims to inform better decision-making, ensuring that policy appraisals fully take into account costs and benefits to the natural environment. However, valuing ecosystem services in monetary terms is often difficult and controversial, particularly for many regulatory services and ecosystem processes for which the direct benefits to people are not clear (Wainger *et al.*, 2010). Some argue that a monetary framework helps to shift context from 'nature free' to 'nature valuable', and can enhance the efficiency of policy. Others feel that it is inappropriate, unethical or dangerous, shifting focus from real ecological changes to monetary changes, and from sustainability constraints to trade-offs (RUBICODE, 2008). It is important to bear in mind that these methods are merely tools for aiding thinking and decision-making, and that the ecosystem services approach does not necessarily or logically entail the monetary approach. However, the ways we identify and categorise ecosystem services are not value-free, nor are they independent of the social and economic organisation of societies (RUBICODE, 2008).

There are also non-economic approaches to valuing ecosystem services, which involve the use of deliberative techniques to explore public opinion or make decisions, such as citizens' juries and citizens' panels. In these, participants are asked to consider different arguments and come to a reasoned conclusion about the best way forward. Such deliberative techniques are often used where the issue is more complex, for instance where competing interests have to be balanced or in other situations where there is no easy answer (e.g. stakeholder involvement in transport policy in the Peak District National Park in England as analysed by Connelly and Richardson, 2009).

In addition, values are themselves dynamic: they change with time and over different temporal and spatial scales, reflecting changes in the perceived importance of services to the different beneficiaries. To place the issue of value dynamics in the MA terminology, the temporal dimension of social benefits derived from ecosystem services varies from direct, short- to medium-term benefits (provisioning) to indirect, medium- to long-term benefits (regulating), to direct, long-term benefits (cultural), to indirect, long- to very long-term benefits (ecosystem processes and properties). The last category of long- to very long-term benefits is what some researchers would prefer to call ecological benefits in contrast to the short- to medium-term socio-economic benefits (e.g. Skourtos *et al.*, in press). Box 4.1 provides further information on the problems of valuation and some of the different terminologies that have been applied in relation to mountain ecosystems and resources.

Building on the work of the MA (2005b) the RUBICODE project addressed all these issues using a more detailed classification of ecosystem types and confining attention to Europe. Within the project, as in the MA, mountain ecosystems were considered as a separate ecosystem category. They are inherently different to other areas because of their altitudinal variations, complex topography and associated habitat mosaics, atmospheric influences and because gravity links higher areas to places below. They are also areas of particularly high biodiversity (e.g. Körner and Spehn 2002; Nagy *et al.*, 2003, Nagy and Grabherr 2009) and cover a considerable proportion of Europe, as discussed in Chapter 1.

4.1 The importance of mountain ecosystem services

Within the RUBICODE project, the relative importance of services provided by mountain ecosystems was ranked into four categories (Table 4.1): key contribution; some contribution; no contribution; and contribution poorly known (Harrison *et al.*, 2010). The last category helps to distinguish where the ranking was based solely on expert opinion (obtained from project workshops and an e-conference, see Harrison *et al.*, 2010); the other rankings were supported by evidence from the literature.

The evidence represents Europe as a whole, acknowledging that the ranking can differ considerably across European mountain regions. Moreover, the ranking is based solely on service supply and does not consider who benefits from the

Box 4.1 Valuing nature: ecosystem services, public goods and externalities

The reason we have to value nature and ecosystem services is choice. In a world of finite (natural) resources, we have to choose among competing uses of these resources and, if necessary, make trade-offs. The criteria for choice can be manifold: economic, moral, cultural, aesthetic, ecological, etc. By the act of choosing we inevitably produce rankings, that is, (relative) values. *Economic values* for ecosystem services are based on human preferences and quantified on the basis of the intensity of these preferences. The intensity of preferences is expressed in the amount of money an individual is willing to pay in order to enjoy a certain level of service provision or the amount of money an individual is willing to accept as compensation in order to tolerate a certain level of loss in the provision of ecosystem services.

In valuing a resource such as an ecosystem, the *total economic value* can be broken down into *use value* and *non-use value*. Use value involves some interaction with the resource, either directly or indirectly. *Indirect use value* derives from regulating services provided by the ecosystem: for example, the removal of nutrients to provide cleaner water to those downstream, or the prevention of downstream flooding. *Direct use value,* on the other hand, involves interaction with the ecosystem functions themselves. It may be the consumption of goods such as the harvesting of fish or game animals, or it may be the consumption of services such as some recreational and educational activities. *Non-use value* is associated with benefits derived simply from the knowledge that a resource, such as an individual species or an entire ecosystem, is maintained. Non-use value is closely linked to ethical concerns and can be split into three basic components, although these may overlap depending upon exact definitions: *Existence value* can be derived simply from the satisfaction of knowing that some feature of the environment continues to exist, whether or not this might also benefit others. *Bequest value* is associated with the knowledge that a resource will be passed on to descendants to maintain the opportunity for them to enjoy it in the future. *Philanthropic value* is associated with the satisfaction from ensuring resources are available to contemporaries of the current generation.

Finally, some values may be entirely disassociated with the concept of choice (or trade-off). These are *intrinsic values* (as opposed to instrumental values where the option of a trade-off exists) and may be given to items or beings that are to be preserved on their own right, irrespective of them serving any user-specified goals, objectives or conditions, or that are so important for life itself, that no trade-off is tolerable.

All the above explanation summarises the definitions and context of valuation of ES for all major ecosystem types in Europe as refined and adopted by the RUBICODE project and consistent with the MA (Harrington *et al.*, in press). However, there are other, parallel terminologies and definitions presently in use in the literature that specifically address mountain ecosystems and their resources. These are exemplified in a report by Robinson (2007), who refers to *externalities*, which he defines as 'side effects of an economic activity such as agriculture'. Externalities directly affect the production or consumption conditions of economic actors and hence are external to the market: they cannot be bought and sold as they are not priced. If a market for an externality is created, it is transferred, or '*valorised*' to become *internalised* and given monetary value as part of the economic market, and economic activity may increased in positive externalities. For example, a cultural mountain landscape created by traditional agricultural practices is valorised when images of the landscape are used to market local dairy products or honey. Distinction is made between positive (e.g. flood prevention) and negative (e.g. causing floods) externalities resulting from economic activities. Many externalities are also *public goods:* things that do not have a price as nobody can be excluded from its consumption (Cornes and Sandler, 1996). In economic terms, public goods are determined by their excludability (to what extent is it possible to prevent someone from benefiting from the resource?) and rivalry (do people compete for using the resource?). Thus clean air is supposed to represent a 'pure' public good because everyone has access to it, although this is not true for smog in towns or cities in mountain valleys, particularly during winter temperature inversions, e.g. Innsbruck in Austria (Schicker and Seibert, 2009).Water is a less pure public good because some people can be excluded by building dams or diverting water courses, although, this too is a naive view that does not consider drought situations, even in mountains. Rivalry simply refers to competition between people for the amount, or quality of a particular resource which must be limited in some way, which is the very basis of valuation as discussed here.

These descriptions, although they give some general notions of the issues at hand, are mostly too imprecise in the present context: They are not well suited to dealing with the mix of socio-economics, ecosystems and ecosystem processes and indeed can lead to confusion. Thus ecosystem services and the 'ecosystem approach' to valuation, as developed by RUBICODE and adopted here, is to be advocated as a clear means

Box 4.1 Valuing nature: ecosystem services, public goods and externalities (cont.)

of understanding and communication across the disciplines (Harrington *et al.*, in press). The approach and terminology has been put forward as consistent with the principles and workings of the CBD and MA, which are both familiar to and well accepted by policy makers (Harrington *et al.*, in press). However, it is not the intention here, to attempt to map this typology onto those used by others. In this new and developing area of work, there are still gaps in knowledge that need to be addressed (Anton *et al.*, in press) and terminologies will continue to evolve (Harrington *et al.*, in press).

Source: John Haslett (University of Salzburg, Austria).

service (including highland-lowland interactions), cost-benefit ratios of service protection, threats to the service, or the availability of human-derived alternatives to service production.

It may be seen from Table 4.1 that, for all the ecosystem services considered, mountain ecosystems are thought to give either a key or at least some contribution to service provision, or the contribution is poorly known. In other words, the 'no contribution' column is blank throughout; there is no service on the list for which mountain ecosystems were identified as of no relevance. This gives further emphasis to the multifunctionality of European mountains as noted above.

Table 4.1 Qualitative ranking of importance for services within European mountain ecosystems, as revealed by the RUBICODE Project

MA category	Ecosystem service	Key contribution	Some contribution	No contribution	Poorly known
Provisioning services	Food and fibre	X			
	Timber/fuel/energy	X			
	Freshwater	X			
	Ornamental resources		X		
	Biochemicals/natural medicines		X		X
	Genetic resources	X			X
Regulating services	Pollination		X		X
	Seed dispersal		X		X
	Pest regulation		X		X
	Disease regulation		X		X
	Invasion resistance				X
	Climate regulation	X			
	Air quality regulation	X			
	Erosion regulation	X			
	Natural hazard regulation	X			
	Water flow regulation	X			
	Water purification/waste treatment		X		X
Cultural services	Spiritual and religious values		X		
	Education and inspiration	X			
	Recreation and ecotourism	X			
	Cultural heritage	X			
	Aesthetic values	X			
	Sense of place	X			

Note: If no documented evidence exists to support key/some contribution then this is indicated by an additional 'X' in the 'poorly known' column.

Source: Extracted from Harrison *et al.*, 2010.

4.1.1 *Provisioning services*

In Europe, although food is primarily produced in intensively managed agro-ecosystems, traditional extensive agricultural practices in European mountains continue to provide foods (such as dairy products, meat and honey), and more intensive agriculture is also practised on fertile valley floors (e.g. in the Alps; Staub *et al.*, 2002). Furthermore, wild populations of animals and plants are harvested to provide foods, such as game, fish, berries and mushrooms. All these food products are particularly important to local communities for their own consumption and for marketing further afield. Some mountain areas are a source of wool fibre from grazed sheep, but many fibres are now imported from outside the EU.

Mountain forests are major providers of timber and wood fuel, globally (Körner *et al.*, 2005) and in European mountains such as the Alps (Ciais *et al.*, 2008, Stöhr 2009) and Carpathians (Box 4.2). Recently, wood pellets have become a significant alternative fuel source for domestic and industrial use in some countries (e.g. Saracoglu and Gunduz, 2009). A further source of energy comes from the many mountain rivers in Europe that are dammed for hydropower generation and hence make a key contribution to energy supply (WCD, 2000; Euromontana 2010). Hydropower generation continues to increase in Europe (Lehner *et al.*, 2009), influenced by an increasing trade in green energy.

The provision of freshwater is also a key contribution from mountain ecosystems. Abiotic characteristics of mountain ecosystems provide this service. Thus mountains act a water pump by pulling moisture from rising air masses, which they collect in their watersheds and then store and distribute, thus acting as 'water towers' (Viviroli *et al.*, 2007; see Chapter 6). Mountain animal and plant biodiversity, on the other hand, often only contribute indirectly to provision of fresh water , as aquatic animals and plants account more for regulating services (e.g. preventing deterioration of water quality or supporting rehabilitation of freshwater resources).

Ornamental resources provided by mountain ecosystems include hunting trophies of game animals such as deer, chamois and some fish, which are still cherished in some communities, both in the mountains and further afield. This may be acceptable as long as the species concerned are not threatened. Also, many plant species are ornamental in gardens and parks, such as alpine species (e.g. edelweiss, numerous alpine cushion plants). However, relative to other provisioning services, ornamental resources are not highly important. Indeed, changes in attitudes and trade regulations across Europe and globally (e.g. the CITES Convention, www.cites.org) mean that demand for some ornamental resources has declined, such as displays of rare butterflies, birds and mammals, and this is to be welcomed.

The contribution of European mountain ecosystems to the provision of biochemical and natural medicines is poorly studied, although mountains are known to be a source of medicinal plants (e.g. arnica and many others: Planta Europa and Council of Europe 2002).

Genetic resources are considered as being of key importance in mountain ecosystems. Globally, mountains include the original genotypes of many crop species, including wheat, which originated in Turkey (Özkan *et al.*, 2002). However, knowledge is limited on the full potential of genetic resources and many are still unrecognised or untapped. Mountains are known to be not only rich in species, but also rich in genetic variability within plant species (Till-Bottraud and Gaudeul, 2002) and within and between insect species, such as Large Blue butterflies (*Maculinea arion*) (Als *et al.*, 2004; Thomas and Settele 2004).

4.1.2 *Regulating services*

Pollination is certainly of some importance in mountain ecosystems because a large proportion of alpine herbs depend heavily on sexual reproduction (Forbis, 2003) and recruitment of alpine vascular plant flora is dependent on a sufficiently abundant and diverse pollinator community (Körner, 1999). However, other alpine plant species are wind-pollinated or are spread vegetatively. On the other hand, pollination services are thought to provide a key contribution to forest ecosystems and to semi-natural grasslands across Europe in general; the actual importance in mountain ecosystems remains poorly known. In order to sustain the abundance and diversity of insect pollinators, preservation or restoration of semi-natural habitats, including flower-rich grasslands, forest edges and forest gaps are essential.

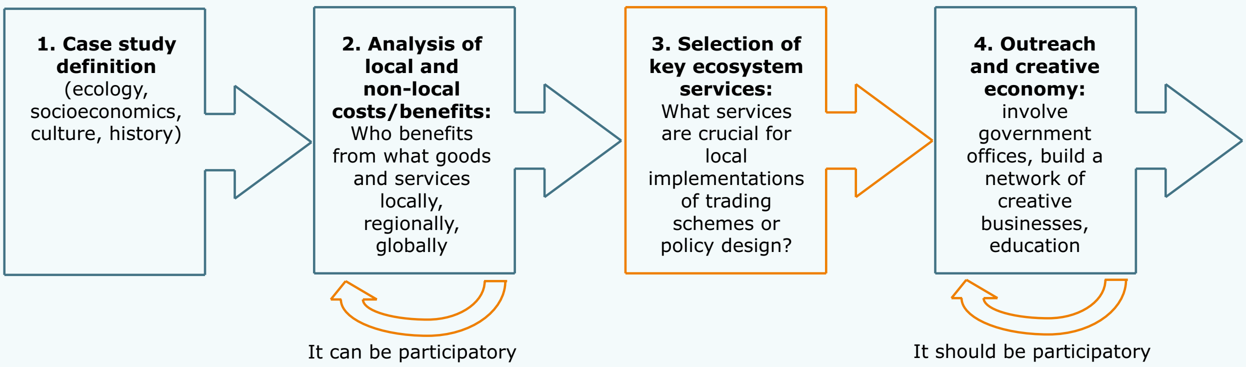
Seed dispersal is a service with some contribution coming from mountain ecosystems, though this is based primarily on expert opinion (Harrison *et al.*, 2010). The service may be of particular relevance in mountain forests, where birds and mammals can act as seed vectors for berry- or nut-producing trees and shrubs (e.g. rowan tree regeneration in subalpine spruce forests, Zywiec and Ledwon, 2008).

Box 4.2 Ecosystem services and the local economy in Maramures Mountains Nature Park, Romania

The Maramures Mountains Nature Park (MMNP) was established in 2005, becoming the largest park in Romania and the second largest protected area in the country, with an area of 133 000 ha. Because of the restrictions imposed and the psychological impact on the people living within the park boundaries, the park administration decided to assess the total value of ecosystem services in the area. The assessment also addressed the potential for this region and its inhabitants to build a lively local economy by taking advantage of recently developed market mechanisms to protect natural resources, such as payments for ecosystem services. Thus, the study provided a key starting point to educate local institutions, organisations, and practitioners, as well as the community living in and around the park, about the contributions of ecosystem services to local and global economies.

The project proceeded in five steps: 1) characterisation of the study area; 2) identification of ecosystem services; 3) selection of key ecosystem services (KES); 4) assessment of economic values for KES and other services; 5) assessment of the potential to capture these economic benefits through payments for ecosystem services to local communities. The approach is summarised in the scheme below, within which, it should be emphasised that stage 2 can be participatory and stage 4 should be participatory.

Figure 4.1 Assessment of ecosystem services: process



The assessment focused on ecosystem services provided by forests, hayfields and alpine pasturelands. The forests cover 90 000 ha, more than half of which are still owned by the state. The study focused mostly on the following ecosystem services provide by forests: regulation of hydrological flows, soil erosion control, water supply, habitats for biodiversity, carbon sequestration, recreation, timber, non-timber forest products, food production (hunting, gathering, fishing), medicinal resources (drugs and pharmaceuticals), and cultural/artistic activities.

Photo: © Costel Bucur
Some ecosystem services provided by forest ecosystems in Maramures Mountains Nature Park, Romania.

The study showed that timber and non-timber forest products have an annual value of 173 USD/ha. Forest services that were evaluated were: carbon sequestration (28.5 USD/ha/yr); water flow regulation (208.7 USD/ha/yr) and soil erosion control (3.3 USD/ha/yr), totalling 240.5 USD/ha/yr. A comparison shows that the services provided by forest ecosystems have a greater value than the forest products coming from them. In an area where logging is a way of life, it is quite difficult to explain the real value of the environment. Nevertheless, due to the high demand for forest products, particularly timber, the study highlights the large responsibility of the new owners of the forests for their proper management and can be used by the park administration to raise awareness and to encourage sustainable use of resources based on scientific basis.

Source: Costel Bucur (Maramures Mountains Nature Park, Romania).

Although mountains appear to present a clear physical barrier to many organisms, their role in invasion resistance remains poorly known. New research will be necessary to clarify how the spread of invasive alien plant and animal species is affected by mountain ecosystems. Similarly, the physical conditions and topography in mountains may act to influence pest and disease regulation, for example, fox distribution patterns and the potential for spread of rabies in the Bavarian Alps (Berberich and d´Oleire-Oltmanns, 1989; and see Haslett, 1990) or ticks carrying Lyme disease in the Northern Italian Alps (Rizzoli *et al.*, 2002). However, there are few studies on the dynamics of other such organisms in European mountains.

European mountains make a key contribution to both climate regulation and closely associated with this, air quality regulation. Large mountain forests play an important role in the global carbon cycle and contribute to climate regulation through the long-term storage of carbon in forest soils and woody biomass (e.g. Ciais *et al.,* 2008). However, there remain many unknowns about the net carbon balance of European forests, which may differ considerably in their ability to act as net carbon sinks, depending on management intensity and policy (Ciais *et al.,* 2008). Articles 3.3 (mandatory afforestation, reforestation and deforestation) and 3.4 (optional forest management strategies for carbon sequestration) of the Kyoto Protocol recognise that forest management can influence the carbon balance. In Europe, 17 countries with large expanses of forest have elected forest management under Article 3.4 (see Nabuurs *et al.*, 2008). Semi-natural grasslands and heathlands and shrub lands in mountains make some contribution to regulating the climate, but biomass production and carbon sequestration tends to be modest due to nitrogen and phosphorus limitation (Niklaus and Körner, 2004).

Air quality regulation is a key service provision in mountains as they extract water from the rising air masses passing over them; this feeds back to regulate the regional climate, and the air mixing is important to air quality regulation. The effects of mountain (or other) forests on air quality outside the tropics are not fully understood (Körner *et al.*, 2005). Mountain agriculture can provide a negative service to air quality regulation due to emissions of nitrogen oxides (NO_X) if soils on valley floors are intensively cultivated, which increases tropospheric ozone (Tilman *et al.*, 2002), ammonia (NH_3) from livestock farming and manure applications, and pesticide drift which can result in the long-distance atmospheric transport of pesticides (EEA, 1995).

Regulation of erosion and natural hazards is of key importance in mountain ecosystems. Due to their topography and often slow-forming, fragile soils, high mountain landscapes are especially vulnerable to irreversible physical changes precipitated by human activities. The instability of upslope areas has a multitude of detrimental effects on human welfare even in the lowlands, including, for example, floods or mudslides (Hewitt, 1997). The only means of securing upslope stability is intact mountain vegetation (Körner, 2002; Quétier *et al.*, 2007), which is likely to be threatened especially by climate warming (Grabherr, 2003; Nagy and Grabherr, 2009) (see Box 4.3).

Mountains are very important in regulating water flow, as discussed in Chapter 6. They store water in glaciers, snowpacks, soil, vegetation and underground aquifers, and regulate water flow by modulating the run-off regime and groundwater seepage. Mountain ecosystems are also important for water purification. Results from study of moss mats in arctic systems (Jones *et al.*, 2002) indicate that the alpine moss flora, which is especially threatened by climate warming and nitrogen deposition, may be particularly important for providing this service.

4.1.3 Cultural services

Mountains provide many cultural services. They may have spiritual or religious values for local inhabitants and/or serve as places of pilgrimage (Bernbaum, 1997; Price *et al.*, 1997). However, religious values in mountains are not considered key in Europe although they can vary by location. For example, many monasteries in Greece and Spain are in mountain regions, while Croagh Patrick Mountain in Ireland is a place of pilgrimage and religious tourism. Humans have inhabited and used mountains for so long that traditional mountain ways of life and the landscape mosaics that have been created result in a strong sense of place and cultural heritage (Messerli and Ives, 1997; Körner *et al.,* 2005). The Alps and other European mountains serve as focal points of international tourism (Godde *et al.*, 2000), to the extent that it is now often detrimental and even destroys those services that originally attracted visitors (e.g. winter sports such as skiing (Wipf *et al.*, 2005), climbing (Hanemann, 2000), and walking and biking). With ever-increasing demand across Europe, identification and conservation of the species and landscape features most relevant to such services are essential for promoting sustainable mountain ecotourism.
For example, mountain rivers and lakes play a significant role in various kinds of recreational

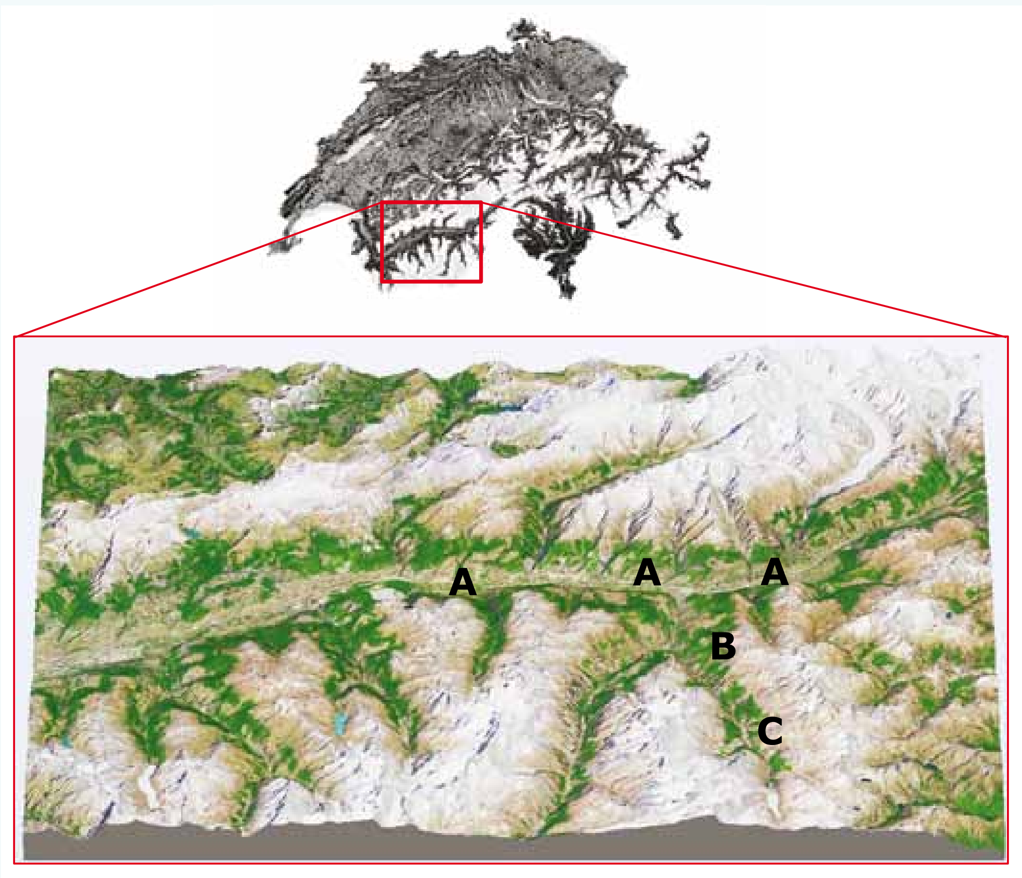
Box 4.3 Impact of climate change on ecosystem services in the Valais, Switzerland

The Rhone valley and the side valleys of the Valais have steep slopes and strong climatic gradients, and are the driest part of Switzerland (Figure 4.2) (Rebetez and Dobbertin, 2004). While native vegetation is adapted to low water conditions, water availability critically influences ecosystem state and the provisioning of ecosystem goods and services.

During the 20th century, the region's economy changed from mainly agriculture-oriented to more industry and particularly service-oriented. However, in the main valley, and at lower elevations, agriculture and wine production are still widely practiced (indicated with A in Figure 4.2). Forests dominate at higher elevations and in the side valleys, providing a range of ecosystem services, particularly protection from gravitational hazards (rockfall in the summer and avalanches in the winter), maintenance of biodiversity, maintenance of recreation/ aesthetic value and, to a lesser degree, timber production (indicated with B and C in Figure 4.2). Tourism has been the major source of revenue in these parts of the Valais for 20–30 years.

Future climate projections suggest that the region will become warmer, with less summer and more winter precipitation. Thus, drought, principally at low elevations, would substantially increase during summer; and the frequency of extremely dry and hot summers would increase (Lindner *et al.*, 2010; Rebetez *et al.*, 2006).

Figure 4.2 The Valais

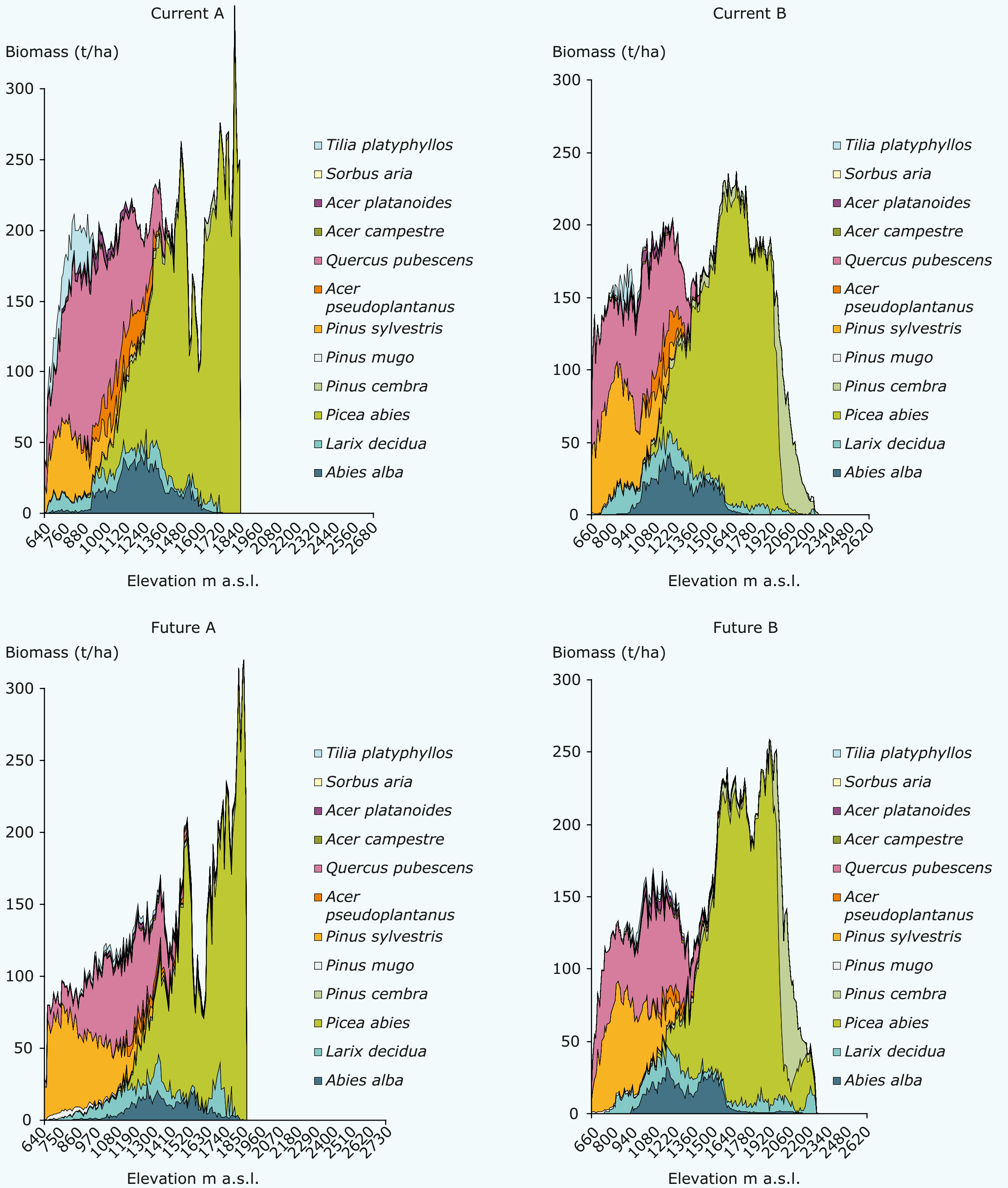


Note: The main Rhone Valley runs through the centre of the region, with industry and agriculture mainly at lowers elevations (A). The impacts of increased temperature and drought on ecosystem services are predicted to be most pronounced in the main valley. Side valleys commonly have steep slopes and are dominated by forests that often provide protection from rock fall and avalanches (e.g. the Saas-Valley, B). Traditionally, grazing and high-elevation agriculture have been practiced at higher elevations. However, as the intensity of these activities has decreased over the past century, parts of these high-elevation areas are being reclaimed by forest (C).

Source: © Atlas of Switzerland 2004.

Box 4.3 Impact of climate change on ecosystem services in the Valais, Switzerland (cont.)

Figure 4.3 Valais forest state for lower elevation areas



Note: (A, corresponding to A in Figure 4.2) and higher elevation areas (B, corresponding to B in Figure 4.2) under current and future climatic conditions. The forest state was derived using the stochastic forest simulation model LandClim. Simulation results represent both the direct impact of climate on forest growth and the indirect impact of increased forest fire disturbances (the expected increase in the virulence of forest pathogens is not included). Local temperature and precipitation data from 1900 to 2000 were used to simulate forest state under current climatic conditions.Future climate data was based on a regional downscaling of the B2 climatic scenario from the third IPCC report. The future forest state is shown for the year 2100.

Box 4.3 Impact of climate change on ecosystem services in the Valais, Switzerland (cont.)

Changes to ecosystem services will be driven directly by shifts in forest structure due to the influence of climate change on growth and competition of forest species, and indirectly through climate-driven shifts in forest disturbances such as wind throw, fire, and pathogens (Schumacher and Bugmann, 2006). The region's steep climatic gradients will strongly influence both the direct and indirect effects of climate change. At lower elevations (< 800 m) the predicted increase in the incidence of droughts will result in species shifts, e.g. *Quercus sp.* becoming more important in the forest, with a decrease in the total forest biomass (indicated with A in Figures 4.2 and 4.3). At intermediate elevations (800–1 400 m), more drought-resistant species would move to higher elevations, with *Picea abies* becoming less abundant (indicated with B in Figures 4.2 and 4.3). At the highest elevations (1 400–2 300 m), the increased temperature would allow total forest biomass to increase, and possibly allow the tree line to move upwards (indicated with C in Figure 4.2 and B in Figure 4.3).

Climate-induced increases in the frequency and intensity of forest disturbances would have a significant impact on ecosystem services. Future increases in summer temperature and a possible increase in strong foehn winds would increase fire risk (Schumacher *et al.*, 2006). While fires, especially larger fires, have historically been more likely at lower elevations, climate change driven shifts in fire risk would have the largest impact at intermediate elevations where drought has the largest impact on fire occurrence (Zumbrunnen *et al.*, 2009). Regional warming and higher summer temperatures would also increase the damage caused by forest pathogens such as pine wood nematodes, bark beetles and fungal agents (Wermelinger *et al.*, 2008). A regional dieback of *Pinus sylvestris*, which began in the 1990s, has been attributed to regional warming that bolstered pathogen populations while simultaneously making trees more susceptible due to increased drought stress (Wermelinger *et al.*, 2008; Dobbertin *et al.*, 2004; Dobbertin and Rigling, 2006).

The impact of these direct and indirect climate factors on ecosystem services will be region- and elevation-specific. As the valleys are steep and the area is quite heavily populated, protection from gravitational hazards is a primary ecosystem service provided by forests. Pathogen-induced mortality of species such as *Pinus sylvestris*, in combination with the predicted decrease in forest biomass at lower elevations (indicated with A in Figure 4.3), would lead to a reduction in the protective function of lower elevation forest. At higher elevations, climate change induced increases in forest biomass will increase the forests' protective function. Increased temperature may also allow the tree line to shift upwards, providing further protection; however, this will be influenced more by land-use practices (e.g. the abandonment of high-elevation pastures) than by direct climate change effects.

The impact of climate change on biodiversity and recreation will similarly be elevation-dependent. At low elevations, increased drought would lower total forest biomass and shift the species composition towards more drought-tolerant species. These combined effects will likely decrease both forest diversity and the diversity of organisms that rely on the forest system. Conversely, at high, and to a lesser degree at intermediate, elevations, climate change is predicted to increase both forest biomass and tree diversity (indicated with B in Figure 4.3). The dynamics of how forests change from their current state to one where drought-resistant species are more dominant will be a key factor that influences ecosystem services in the region.

Source: Ché Elkin and Harald Bugmann (Department of Environmental Sciences, ETH Zurich, Switzerland).

activities, such as bathing, rafting, canoeing, angling, hiking, photography or wildlife viewing. In general, the near-natural and most diverse sections of rivers in their upper reaches within mountain regions are more attractive to people due to their high aesthetic value coupled with a sense of wilderness.

Species diversity in mountains, with many endemic or charismatic animals and plants (Nagy *et al.*, 2003: Chapter 8), together with spectacular landscapes, many with a significant cultural component deriving from centuries or even millennia of human use, are of strong aesthetic value. The associated National Parks, UNESCO Biosphere Reserves and other protected areas in mountains (Chapter 9) provide a structured setting for ecotourism involving the full spectrum of ecosystem types occurring in these environments and also have an important role in education and awareness (e.g. Harmon and Worboys 2004, IUCN 2009). As noted in Box 4.4, they also provide many other ecosystem services.

Box 4.4 Mountain ecosystem services in European protected areas

Europe's mountain protected areas are increasingly recognised not only for their biodiversity but also for their wider social and environmental values, contributing to the delivery of ecosystem services (Stolton and Dudley, 2010; Chapter 9). The earliest objective of ecosystem management in European mountains was usually to prevent disasters from landslides, avalanches or flooding and dates from seven centuries ago when Swiss communes first began to protect key forests. The Swiss government estimates that forests managed for their protective function in the Alps are worth USD 2–3.5 billion per year (International Strategy for Disaster Reduction, 2004). National parks such as Triglav in Slovenia and Hohe Tauern in Austria explicitly recognise the value of such services in their management plans. In Spain, 500 years of regular flooding in Malaga has been stemmed by reforesting part of the catchment above the city and incorporating this into Montes de Malaga Natural Park. The floodplain value of the Dyfi valley, draining the mountains of the Snowdonia National Park in Wales was one reason for its recognition in 2009 as a biosphere reserve by UNESCO.

As noted in Chapter 6, forested catchments provide consistently higher quality water and mountains function as water towers, providing hydropower and irrigation. In Bulgaria, Sofia relies for much of its water on two mountain protected areas — the Rila and Vitosha National Parks. Particularly important is the Bistrishko Branishte Biosphere Reserve, a high mountain peat bog within Vitosha National Park. Other examples are given in Table 4.2.

Table 4.2 Protected areas in mountains supplying water to major European cities

City	Protected area
Vienna, Austria	Donau-Auen National Park (10 000 ha)
Barcelona, Spain	Sierra del Cadí-Moixeró (41 342 ha) Paraje Natural de Pedraforca (1 671 ha)
Madrid, Spain	Natural Park of Peñalara (15 000 ha) Regional Park Cuenca Alta del Manzanares (46 323 ha)
Istanbul, Turkey	WWF is lobbying for forests important for supplying water to be included in protected areas

Mountains also maintain food security through farming, particularly of economically-valuable local breeds and crop varieties. Protected landscapes can serve as models of sustainable production; for example, organic agriculture has been recognised as a particularly useful option within the Mount Etna National Park in Sicily and the Sneznik Regional Park in Slovenia (Stolton *et al.*, 2000). Protected areas also help to conserve agrobiodiversity for crop breeding. This is particularly important in far eastern Europe, where the loss of crop wild relatives (CWR) is a focus for conservation in, for example, Munzur Vadisi National Park, Turkey. Important CWR also occur in other mountains; for example, Sumava National Park in the Czech Republic has been studied as a source of wild fruit tree relatives for crop breeding, and Montseny National Park in Spain conserves several wild *Prunus* species.

More recently, the potential for mountain ecosystems to help mitigate and adapt to climate change has been recognised. European biomes store 100 gigatonnes of carbon (UNEP World Conservation Monitoring Centre, 2008) and forest and peat restoration can recover historical carbon losses. Management choices can increase sequestration. For example, replacement of monocultures with indigenous tree species in Kroknose and Sumava National Parks in the Czech Republic is expected to sequester 1.6 million tonnes of carbon over 15 years (World Resources Institute, 2007). Conversion of uneconomic upland farming to carbon storage and forest management is now being considered for British national parks such as the Cairngorms, Peak District, and Brecon Beacons.

Ecosystem services also have economic and cultural benefits. Tourism is the largest source of income in many mountain areas containing protected areas. In Scotland, the Cairngorms National Park receives around 1.4 million visitors a year, each spending on average GBP 69 (EUR 80) a day on accommodation, food, transport and entertainment. Tourism is often connected to the cultural and spiritual values of mountains, which are linked to ecosystem services; for example, several monasteries actively manage their lands for conservation, as in Rila National Park in Bulgaria and Montserrat National Park in Spain. An understanding of ecosystem values from mountains may create major changes in management priorities in the near future, as exercises such as The Economics and Ecosystems and Biodiversity (TEEB) project (European Communities, 2008) draw increased attention to the value of natural ecosystems.

Source: Nigel Dudley (Equilibrium Research, the United Kingdom).

4.2 Trends in mountain ecosystem services

Trends in the human use and status of services in Europe provided by mountain ecosystems are shown in Table 4.3. Trends are divided into increasing, decreasing, or mixed for human use and enhanced, degraded or mixed for status using the same definitions as the MA (2005a). The MA identified trends for a single time frame from 1950 to 2000, although if the trend had changed within that time frame the most recent trend was indicated (MA 2005a). Analysis of the information for Europe from the literature review and expert opinion of the RUBICODE project revealed that opposing trends were often exhibited in the distant to the recent past in the different major ecosystem types. Hence, trends were divided into two time periods: 1950 to 1990 and 1990 to present. The evidence presented represents Europe as a whole, although if trends differ across European regions this is entered as 'mixed' in Table 4.3 and described below. The availability of evidence varied considerably between services. Very little direct evidence from the literature was found for trends in services in mountain semi-natural ecosystems, and trends were mainly based on expert interpretation of proxies such as changes in habitat area or condition across Europe (Harrison *et al.*, 2010).

There are great variations in the human use and status of different services between mountain regions in Europe. For example, considerable regional differences arise in peoples' attitudes, values and available resources between Western Europe and post-socialist Europe (e.g. Svajda 2008; Szabo *et al.*, 2008). Thus, spatio-temporal trends are mixed, with little distinction between pre- and post-1990 periods. However, there are a few important services that may be exceptions to this and appear to exhibit overall patterns. Demand for timber from mountain forests in Europe has been vast over the last centuries, and remains so today (Ciais *et al.*, 2008; Gimmi *et al.*, 2009; Stöhr, 2009). The MA reports that there has been an overall expansion of natural forest area of 1.2 % in the temperate regions of the world between 1990 and 2000, mainly as a result of increasing forest cover in the mountainous countries of Europe (Körner *et al.* 2005). Similarly, as human demands for clean freshwater continue to increase, mountains remain central to the provision of this pivotal resource (Körner *et al.* 2005). The need for the sustainable delivery of water from mountains is now appreciated, and water regulation not only for human consumption but also to meet industrial needs and energy provision has generally been enhanced.

Recreation and ecotourism have increased dramatically over the last half century. The industry is complex, involving both foreign and domestic visitors. The widespread increases in service use may be attributed to a range of factors, from attractiveness of the region and improved accessibility to the characteristics of the tourists themselves and the expansion of the range of leisure activities (Price *et al.*, 1997). Increases in recreation and tourism have been responsible, to varying extents, for parallel and necessary increases in regulating services on mountains that deal with natural hazard regulation (e.g. avalanches, landslides, floods) and general erosion regulation. A last group of ecosystem services that appears to show a trend, this time in a negative direction, is that provided by pollinators. Though there is little or no documentation specifically for European mountain ecosystems, the recent global decline, which includes Europe, of wild and managed pollinator species, involving both wild and crop plant species in all types of environments (e.g. FAO, 2008) implies a seriously degraded status of pollination services in recent years. The importance of this trend is not to be underestimated, as pollination services regulate and are essential for the provision of many of the other services in mountain ecosystems.

4.3 Mountains, ecosystem services and the future

This chapter demonstrates that European mountains and their ecosystems provide many important services from each of the main MA categories, underlining the characteristically very high multifunctionality of these systems. Importantly, services in each category are included that make specific contributions to lowland as well as highland beneficiaries. Indeed, the MA stresses the major social and economic consequences of highland-lowland links, observing that, while people and industries in the lowlands tend to invest to harness highland opportunities largely for their own benefit, maximising highland-lowland complementarities is crucial to both communities. People making their living in mountains need linkages to lowland markets, while lowland inhabitants rely on mountain people to serve as stewards for maintaining the provision of mountain ecosystem services (Körner *et al.*, 2005).

However, it is important to stress that it is not only the economic trade-offs among the relevant beneficiaries. It is also essential to consider the biological side, including the need to maintain and protect ecosystem service providers (ESPs) and the full spectrum of biodiversity and ecosystem function and integrity (Harrison *et al.*, 2010; Haslett *et al.*, 2010), recognising the dynamic nature of ecosystems and present conditions of environmental change. Here again, trade-offs between the biological ESPs are unavoidable, as a provider for one ecosystem service may antagonise a service by another. For example, complex vegetation provides slope stability (Körner, 2002), but management to maintain this runs contrary to the creation and management of smooth ski slopes (Wipf *et al.*, 2005). These different roles then affect the levels of service provision to the beneficiaries. Given the complex relationships between ecosystem providers and human beneficiaries, a balance of cost-benefit trade-offs is required for conservation and production that is associated with different land management options (Luck *et al.*, 2009). To this end, a new conceptual framework has been developed to assess the impacts of drivers of environmental change on provision of ecosystem service and societal responses, to enable them to be managed and protected more effectively. The framework, known as FESP (Framework for Ecosystem Service Provision), is based on an interpretation of the widely-used Drivers-Pressures-State-Impact-Response (DPSIR) framework and is set within the context of entire social-ecological systems (see Rounsevell *et al.*, in press, for a full account). The value of such a common framework lies in making the comparison across competing services accessible and clear as well as highlighting the conflicts and trade-offs between both multiple ecosystem services and also multiple service beneficiaries.

The FESP approach also illustrates the need to consider biodiversity conservation and ecosystem services together. This is contrary to traditional nature conservation philosophy, which was undertaken solely for the moral, ethical, or aesthetic reasons that are equivalent to the 'cultural services'

Table 4.3 Ecosystem services in the EU

Services \ Ecosystems	Agro ecosystems	Forests	Grasslands	Heath and scrubs	Wetlands	Lakes and rivers
Provisioning						
Crops/timber	↓ (Mixed)	↑ (Enhanced)	(Not applicable)	(Not applicable)	↓ (Degraded)	(Not applicable)
Livestock	↓ (Mixed)	= (Degraded)	= (Degraded)	= (Degraded)	↓ (Degraded)	(Not applicable)
Wild foods	= (Degraded)	↓ (Degraded)	↓ (Degraded)	(Unknown)	= (Mixed)	(Unknown)
Wood fuel	(Not applicable)	= (Mixed)	(Not applicable)	= (Degraded)	(Not applicable)	(Not applicable)
Capture fisheries	(Not applicable)	(Not applicable)	(Not applicable)	(Not applicable)	= (Degraded)	= (Degraded)
Aquaculture	(Not applicable)	(Not applicable)	(Not applicable)	(Not applicable)	↓ (Degraded)	↓ (Degraded)
Genetic	= (Degraded)	↓ (Mixed)	↓ (Degraded)	= (Degraded)	= (Mixed)	(Unknown)
Fresh water	(Not applicable)	↓ (Degraded)	(Unknown)	(Unknown)	↑ (Mixed)	↑ (Mixed)
Regulating						
Pollination	↑ (Mixed)	↓ (Degraded)	= (Degraded)	(Unknown)	(Not applicable)	(Not applicable)
Climate regulation	(Not applicable)	↑ (Enhanced)	(Unknown)	= (Mixed)	= (Degraded)	= (Degraded)
Pest regulation	↑ (Mixed)	(Unknown)	= (Degraded)	(Not applicable)	(Unknown)	(Not applicable)
Erosion regulation	(Not applicable)	= (Mixed)	= (Degraded)	= (Degraded)	(Unknown)	(Unknown)
Water regulation	(Unknown)	= (Mixed)	(Unknown)	↑ (Mixed)	↑ (Enhanced)	= (Degraded)
Water purification	(Not applicable)	(Unknown)	(Unknown)	(Unknown)	= (Mixed)	= (Degraded)
Hazard regulation	(Not applicable)	(Unknown)	(Unknown)	(Unknown)	= (Mixed)	= (Degraded)
Cultural						
Recreation	↑ (Mixed)	= (Mixed)	↓ (Degraded)	↑ (Mixed)	↑ (Mixed)	= (Mixed)
Aesthetic	↑ (Mixed)	= (Mixed)	= (Degraded)	= (Degraded)	↑ (Mixed)	= (Degraded)

Status for period 1990–present Degraded Mixed Enhanced Unknown Not applicable

Trend between periods

↑ Positive change between the periods 1950–1990 and 1990 to present

↓ Negative change between the periods 1950–1990 and 1990 to present

= No change between the two periods

Note: Ecosystem services still degrading. Most of the ecosystem services in Europe are judged to be 'degraded' — no longer able to deliver the optimal quality and quantity of basic services such as crop pollination, clean air and water, and control of floods or erosion (RUBICODE project 2006–2009; marine ecosystems not included).

of the MA. There is now a recognised strong interplay between conservation and economics in the other MA service groups (i.e. provisioning and regulating services). This means that managing habitats to protect service provision, while at the same time meeting the needs of biodiversity conservation may provide a 'value-added' strategy to complement and support existing biodiversity conservation (Harrison *et al.*, 2010; Haslett *et al.*, 2010). In addition, strategies to conserve ecosystem service provision involve a range of types and sizes of target units, from single populations to functional groups to entire species assemblages and habitat complexes at the landscape level, as well as how they change in space and time. Thus the approach is intrinsically dynamic, particularly as the target units are not always spatially fixed: service provision must follow environmental change and there is a need to be able to deal with projected changes. This is particularly true for Europe's mountains as habitats and species shift altitudes and run out of suitable climate space in the future (Section 8.3).

A framework was developed within RUBICODE to bring together the relationships between present conservation approaches, wider societal needs, the provision of ecosystem services and dynamic ecosystems (Haslett *et al.*, 2010). The framework involves the integration of appropriate policy and management for service provision in different sectors with ecosystem sustainability and integrity so as to provide biodiversity conservation within the framework of a Social-Ecological System, as with FESP. Such conservation strategies must also encompass management for sustainable ecosystem services, whilst still maintaining ecosystem integrity. This then reflects, and may influence, changing societal needs. The framework operates as a continuous, iterative process with dynamic and adaptive properties. However, it is of utmost importance that management for the protection of sustainable service provision be closely linked to existing conservation strategies and policy in all appropriate places and at all scales of organisation. This ensures that services whose provision will be antagonistic to conservation interests or to other services do not have severe detrimental effects on biodiversity. While ecosystem service provision has begun to creep into some aspects of European Conservation Strategy (e.g. Haslett, 2007), the whole will require a focus on governance and institutions and increased communication and integration across the different sectors, from agriculture and forestry to industry, transport and recreation.

The implications of these new developments for mountain ecosystem management, sustainable ecosystem service provision and biodiversity conservation are considerable. The potential of adopting the ecosystem services approach in the conservation of the mountains and uplands of the United Kingdom has already been clearly acknowledged and is addressed in some detail by Bonn *et al.* (2009). A more general commentary on the use of ecosystem services within the Ecosystem Approach to biodiversity conservation of the Convention on Biodiversity (CBD), but specifically addressing the UK situation is provided by Haines-Young and Potschin (2008). Now, new frameworks, that were not available to these authors, exist, but they have yet to be applied, tested and refined in mountain (and other) situations. This is one of the important next logical steps in this rapidly developing field.

5 Climate change and Europe's mountains

Europe's mountains stretch from the Arctic through the temperate and into the subtropical climatic zone of the Northern hemisphere, as well as from maritime to continental environments. As such, they encompass a wide range of bioclimatic zones. Across these very diverse mountains, local climatic and other environmental controls vary enormously as their effects are superimposed upon macro-scale factors influencing mountain climates, such as continentality and latitude. Recognising the sensitivity of mountain environments and the potential vulnerabilities of these environments to climate change, the scientific community has increased research on global change in mountain regions including the possible impacts of anthropogenic climate change (Becker and Bugmann, 2001; Huber *et al.*, 2005; EEA, 2009). This chapter presents recent observed changes in the climate of Europe's mountains and likely changes during this century. The likely impacts of these changes on glacier, hydrological and ecological systems are presented in Box 6.2 and Sections 6.5, 6.6, and 8.3, respectively.

5.1 Changes in climate across Europe

The availability of climatic data across Europe's mountain regions is highly variable in both space and time, with particularly high spatial density and length of record in the Alps, and lower densities and lengths of record in other mountain regions (Price and Barry, 1997). Consequently — and also because the spatial resolution of Global Climate Models (GCMs) generally does not permit detailed prediction of climates of regions such as mountains, and relatively few studies using statistical downscaling methods or regional climate models have considered mountain areas — this introductory section mainly presents data for Europe as a whole, rather than mountains specifically, to provide a context for the following sections.

5.1.1 Observed changes in climate

Observations of increases in global average air and ocean temperatures, widespread melting of snow and ice, and rising sea level are unequivocal evidence of warming of the climate system globally. Direct observations and proxy records indicate that historical and recent changes in climate in many mountain regions are at least comparable with, and locally may be greater than, those observed in the adjacent lowlands. Global mean temperature has increased by 0.8 °C compared with pre-industrial times for land and oceans, and by 1.0 °C for land alone (EEA, 2008). Most of the observed increase in global average temperatures is very likely due to increases in anthropogenic greenhouse gas concentrations (Albritton *et al.*, 2001). During the 20th century, most of Europe experienced increases in average annual surface temperature (average increase 0.8 °C), with more warming in winter than in summer (IPPC, 2007). European warming has been greater than the global average, with more pronounced warming in the southwest, the northeast, and mountain areas. As the observed trend in western Europe over the past decade appears stronger than simulated by GCMs, climate change projections probably underestimate the effects of anthropogenic climate change (van Oldenborgh *et al.*, 2009).

5.1.2 Projected regional changes

Landmasses are expected to warm more than the oceans, and northern, middle and high latitudes more than the tropics (Giorgi, 2005, 2006; Stendel *et al.*, 2008; Kitoh and Mukano, 2009; Lean and Rind, 2009). Warming in the atmosphere is also expected to be more pronounced at progressively higher elevations in the troposphere, along a latitudinal gradient from the northern mid-latitudes to approximately 30 °S, with a maximum above the tropics and sub-tropics (Albritton *et al.*, 2001). Many European mountain regions are situated in these high-latitude zones of anticipated enhanced warming.

Projections from GCMs generally show increased precipitation at high latitudes (Frei *et al.*, 2003). With more precipitation falling as rain rather than snow in a warmed atmosphere, soil moisture in northern areas in winter would increase, while in summer, simulations suggest a general tendency towards mid-latitude soil drying (Christensen, 2001). Despite possible reductions in average summer precipitation over much of Europe, precipitation amounts exceeding the 95th percentile are very likely in many areas, thus episodes of severe flooding may become more frequent despite the general trend towards drier summer conditions (Christensen and Christensen, 2002; Christensen, 2004; Pal *et al.*, 2004; Frei *et al.*, 2006).

The details of outputs from different models vary, and so ensemble-based approaches have been used to bring together outputs from a range of models. In such an approach using outputs from 20 GCMs for three of the emission scenarios of the Inter-Governmental Panel on Climate Change (IPCC), the Mediterranean, northeast and northwest Europe are identified, in this order, as warming hot spots (Giorgi, 2006), albeit with regional and seasonal variations in the pattern and amplitude of warming (Giorgi and Lionello, 2008; Faggian and Giorgi, 2009; Brankovic *et al.*, 2010).

Most climate change studies for mountain areas rely on simulations of the future climate using statistical downscaling models (SDMs) or regional climate models (RCMs) forced by boundary data from GCMs. Table 5.1 lists RCM-based studies for different European regions, some of which evaluate model performance in mountainous areas. RCMs also project rising temperatures for Europe until the end of the 21st century, with an accelerated increase in the second half of the century. However, for many regions, there are substantial differences between the RCM surface temperature and precipitation simulations, depending on the driving GCM. There is no clear correlation of differences with regions, but the driving GCM has a dominant effect on temperature during spring, winter, and autumn, which seems to be larger than the effect of the specific RCM (Christensen and Christensen, 2007). For precipitation, the driving model seems to be relatively most important in spring and summer (Christensen and Christensen, 2007; Déqué *et al.*, 2007). Despite the complex local character of simulated summertime change in RCMs, the larger-scale pattern shows a gradient from increases in Northern Scandinavia to decreases in the Mediterranean region (Frei *et al.*, 2006; Schmidli *et al.*, 2007). In contrast, increases in wintertime precipitation primarily north of 45 °N are a robust feature of RCM projections over Europe, with decreases over the Mediterranean (Frei *et al.*, 2006; Schmidli *et al.*, 2007; Haugen and Iversen, 2008). Overall, therefore, there is likely to be an increase in precipitation in the north and a decrease in the south, with all models agreeing in the north, and 12 out of 16 models agreeing in the south (van der Linden and Mitchell, 2009).

The previous paragraphs refer to changes in mean values. However, for both ecological and human systems, changes in extremes may be far more important (Box 5.1). With regard to temperatures, biases in maximum temperatures during summer, and minimum temperatures during winter, tend to be larger at the extremes than in the mean values (Beniston *et al.*, 2007; Hanson *et al.*, 2007). RCMs generally underestimate maximum temperatures during summer in northern Europe and overestimate them in eastern Europe (Frei *et al.*, 2006). In winter, minimum temperatures are overestimated over most of Europe. The spread between the models is generally also larger at the tails of the probability distributions (Frei *et al.*, 2006). With regard to precipitation, simulated change in extremes from various RCMs shows a seasonally-distinct pattern (Frei *et al.*, 2006; Jacob *et al.*, 2007; Koffi and Koffi, 2008). In winter, land north of about 45 °N would experience an increase in multi-year return values, and the Mediterranean region would experience small changes, with a general tendency towards decreases (Hanson *et al.*,

Table 5.1 Recent literature, RCM projections and evaluations for European mountain regions

Year	Author	Literature type	Type of study	Region addressed
2003	Frei *et al.*	Journal paper	RCM evaluation	European Alps
2006	Schmidli *et al.*	Journal paper	Downscaling methods comparison	European Alps
2007	Coll	Unpublished PhD thesis	RCM evaluation	Scottish Highlands
2007	Schmidli *et al.*	Journal paper	Downscaling methods comparison	European Alps
2008	Lopez-Moreno *et al.*	Journal paper	RCM inter-comparison	Pyrenees
2008	Noguez-Bravo *et al.*	Journal paper	GCM projections	Mediterranean mountains
2009	Smiatek *et al.*	Journal paper	RCM inter-comparison	European Alps

2007). The increase in wintertime precipitation extremes is a robust feature in RCM projections over Europe, whereas the character of change for summer is more complex (Beniston *et al.*, 2007; Christensen and Christensen, 2007; Déqué *et al.*, 2007; Schmidli *et al.*, 2007; Lopez-Moreno *et al.*, 2008). The larger-scale pattern shows a gradient from increases in northern Scandinavia to decreases in the Mediterranean region which is fairly similar between models. Addressing uncertainty in scenarios of summer precipitation extremes is a research priority (Frei *et al.*, 2006).

Box 5.1 Climate change and extreme events in the mountains of northern Sweden

Climate warming in the Swedish sub-Arctic since 2000 has reached a level where the current warming has exceeded that of the late 1930s and early 1940s and, significantly, has crossed the 0 °C mean annual temperature threshold that causes many cryospheric and ecological impacts. The accelerating trend of temperature increase has driven trends in snow thickness, loss of lake ice, increases in active layer thickness, and changes in tree line location and plant community structure. Changes in the climate are associated with reduced temperature variability at the seasonal scale, particularly a loss of cold winters and cool summers, and an increase in extreme precipitation events that decrease the stability of mountain slopes and cause infrastructure failure. Both mean annual precipitation and extreme precipitation events have increased, especially the number of days with more than 20 mm precipitation.

Even more important from a landscape change perspective, the 'extremes of the extremes' have also increased. Except from one extreme precipitation event in the 1920s, these extremes have reached higher and higher levels, with increasing daily maxima up to 60 mm. Several of the geomorphological and hydrological impacts of these extreme events are well known in the Abisko area, where both a railroad and a road pass close to mountain slopes. The extreme precipitation events have caused disturbances for traffic; the latest extreme precipitation event, on 20 July 2004, triggered a number of debris flows and landslides and, for the first time in this area, badly damaged a road bridge. Parts of the road-bank were eroded and transported away by the running water, and it was only because of an attentive driver that severe car accidents were avoided. The trajectory of increasing extremes of extremes over time renders the planning, building and meteorological concept of 'return frequency' of extreme events obsolete, as each new extreme has not been experienced earlier in the instrumental record. Planning adaptation to climate change therefore requires the formulation of new concepts and building guidelines.

Not only *precipitation* affects and causes changes in these landscapes; extreme *temperature* events are also occurring more frequently in winter. Experimental studies and findings from observations following natural events show that short winter warming events can cause major damage to plant communities even at the landscape scale. In such an event in December 2007, the temperature rose to 7 °C within a few days, resulting in more or less complete loss of the snow cover and hence exposure of the vegetation when low temperatures returned. After a short period of no or little snow cover, the temperature fell and, a few days later, the vegetation was again covered by snow. This single warming event, about 10 days long, caused substantial impacts to the vegetation cover. In the following summer, satellite-derived Normalised Differential Vegetation Index (NDVI) showed damage of dwarf shrubs over almost 15 000 km². Field studies in the affected areas showed that the frequency of dead roots of the dominant shrub, *Emperum hermaphroditum*, increased up to 16-fold, resulting in almost 90 % less summer growth compared with undamaged areas. Similarly, field experiments using infra-red heating lamps and soil warming cables to simulate extreme temperature events have shown that single-day snow-free conditions followed by freezing result in c. 20 times greater frequency of dead roots and almost 50 % less shoot growth of *E. hermaphroditum* and near complete absence of berry production in *Vaccinium myrtillus*.

These events are of major concern both for conservation — as animals such as lemmings that depend on continuous snow cover decline, resulting in loss of predators such as the snowy owl and arctic fox — and for the reindeer-herding Sami, as damaged vegetation needs to be replaced by alternative pastures or expensive supplementary food pellets.

Source: Christer Jonasson and Terry Callaghan (Abisko Scientific Research Station, Sweden).

5.2 Changes in climate in European mountains

5.2.1 Long-term trends in climatic variables

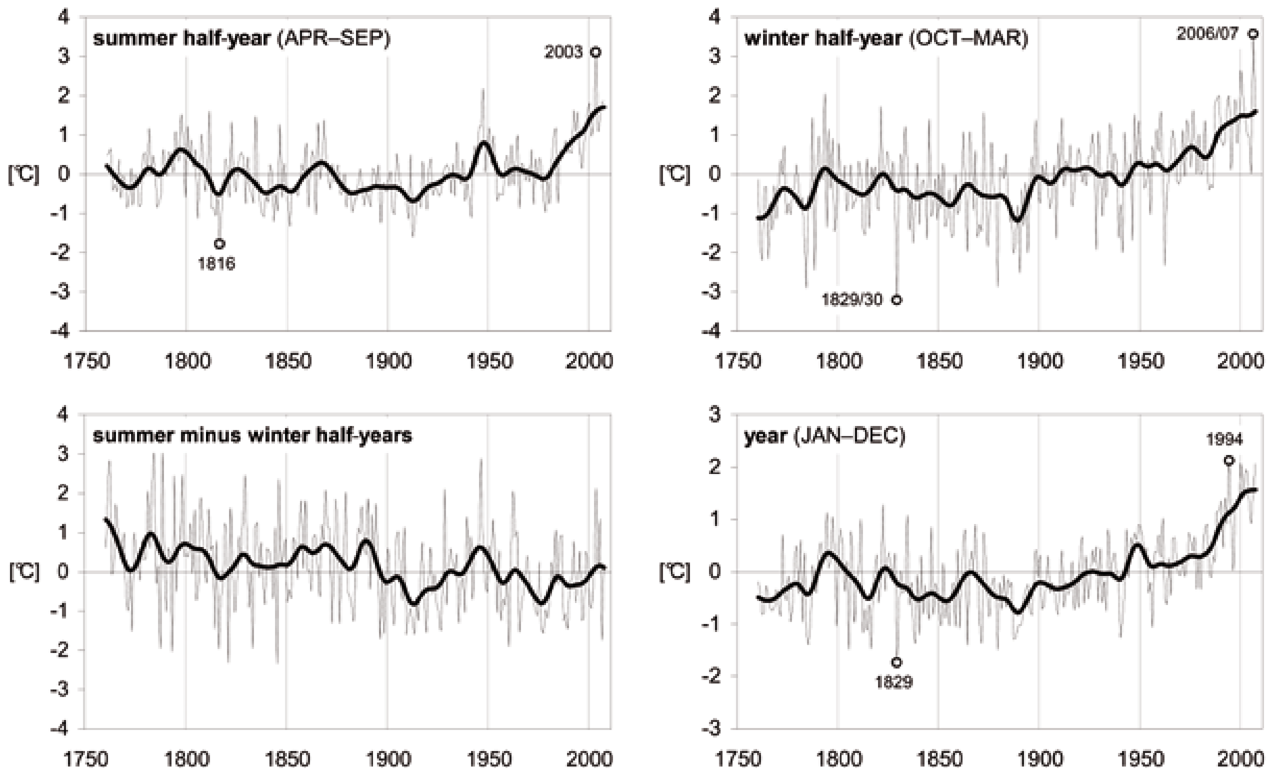
Evidence of recent climate change comes from observations at high-altitude sites across the globe, with observed changes including increased winter rainfall and rainfall intensity (Groisman *et al.*, 2005; Malby *et al.*, 2007) and temperatures increasing more rapidly than at lowland sites, particularly through increases in minimum (nocturnal) temperatures (Bradley *et al.*, 2006). However, evidence of altitude-based differences in warming is not equivocal (Pepin and Seidel, 2005). Actual and potential responses in cryospheric variables include: a rise in the snowline; a shorter duration of snow cover (Martin and Etchevers, 2005); changes in avalanche frequency and characteristics; glacier recession (Haeberli, 2005; Box 6.2); break-out of ice-dammed lakes; warming of perennially-frozen ground; and, thawing of ground ice (Barry, 2002; Harris *et al.*, 2003; Harris, 2005).

As noted above, the availability of climate data is greatest for the Alps (EEA, 2009). A compilation of 87 temperature records, with documentary and narrative reports and gridded reconstructions, some dating back to 1500, shows that 1994, 2001, 2002 and 2003 were the warmest years in the record (Casty *et al.*, 2005). Over the past 250 years, in the Greater Alpine Region (GAR):

- there has been an overall annual temperature increase of ~ 2.0 °C from the late 19th to early 21st century;
- following a decrease in temperature from 1790 to 1890, 20th century warming was more pronounced in summer than in winter;
- during the past 25 years, winters and summers have warmed at comparable rates, leading to an annual mean temperature increase of 1.2 °C, an increase unprecedented in the instrumental record (Zebisch *et al.*, 2008).

While temperature changes have followed similar patterns across the Alps (Figure 5.1), trends at the

Figure 5.1 Change in temperature for the Greater Alpine Region, 1760–2007: Single years and 20-year smoothed mean series



Note: Single years (thin lines) and 20-year smoothed means (bold lines). All values relative to 1851–2000 averages, summer and winter half-years (first row), annual means and annual range (second row).

Source: ZAMG-HISTALP database (version 2008, including the recent Early Instrumental (EI) period correction (Böhm *et al.*, 2009).

sub-regional scale are different for precipitation (EEA, 2009; Figure 5.2). Over the past two centuries, there has been a trend of increasing precipitation in the north-west Alps (eastern France, northern Switzerland, southern Germany, western Austria) and a decreasing precipitation in the south-east (Slovenia, Croatia, Hungary, south-east Austria, Bosnia and Herzegovina) (Auer *et al.*, 2005).

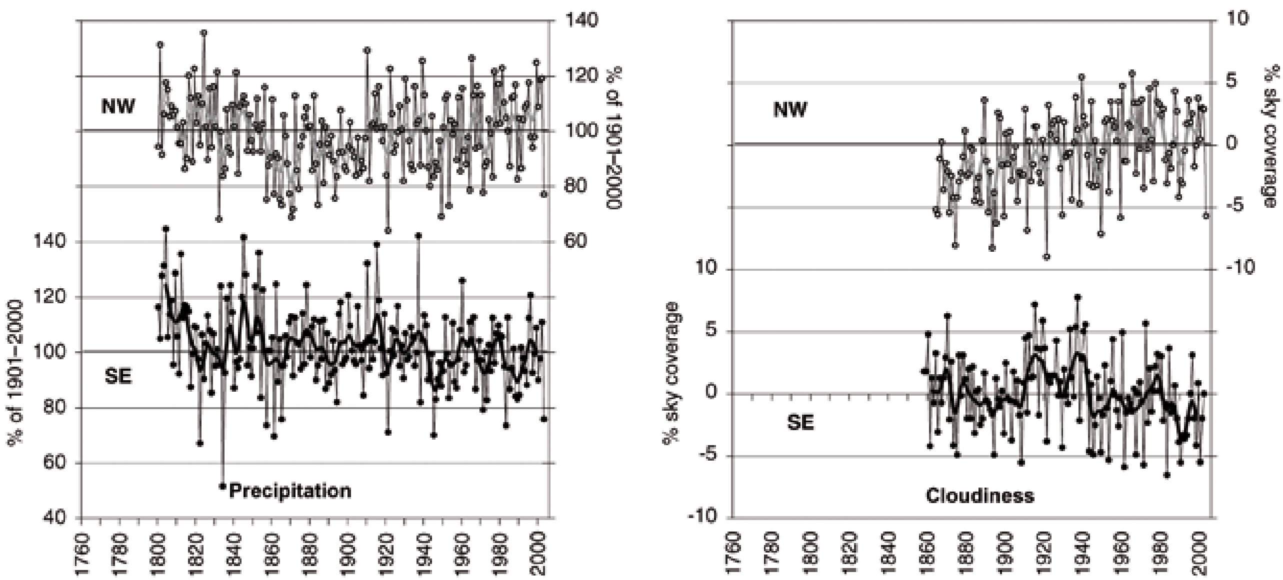
The frequency of temperatures exceeding the freezing point during the winter season in eastern Switzerland has more than doubled during periods of high North Atlantic Oscillation (NAO) index, compared to periods with low index values, thereby increasing the chances of early snowmelt. Despite strong inter-annual variability, overall trends in snow cover have not changed much, as the rate of warming during the 20th century is modest in relation to future projections (Beniston, 2006). However, the upper tens of metres of permafrost warmed by 0.5 °C to 0.8 °C during the 20th century (Gruber *et al.*, 2004), especially at higher altitudes, with accompanying thickening of the seasonal active layer (Harris *et al.*, 2009).

After the Alps, the longest records and most dense networks are in parts of the Carpathians, the mountains of the British Isles, and the mountains of Scandinavia (Price and Barry, 1997). Changes have also been observed for areas of the more maritime UK uplands, including evidence of more rapid warming (Holden and Adamson, 2002) and marked precipitation changes (Barnett *et al.*, 2006; Fowler and Kilsby, 2007; Maraun *et al.*, 2008). In the Carpathians, annual temperature variability increased from 1962 to 2000 (e.g. from 0.3 °C to 0.5 °C in the Bucegi Mountains; from 0.5 °C to 0.7 °C in the Semenic Mountains; and, from 0.8 °C to 0.9 °C in the southern Carpathians and Apuseni Mountains (Ionita and Boroneant, 2005; Micu, 2009)). At other Carpathian locations, winter temperature increases of ~ 3 °C characterised the end of the 1961–2003 period compared to the long-term average (Micu and Micu, 2008; Micu, 2009).

Central European station data for 1901–1990 and 1951–1990 indicate that mountain stations show only small changes of the diurnal temperature range from 1901 to 1990, while low-lying stations in the western Alps show a significant decrease in the diurnal temperature range, caused by a strong increase in the minimum temperature. For 1951–1990, the diurnal temperature range decreased at the western low-lying stations, mainly in spring, but remained roughly constant at the mountain stations (Weber *et al.*, 1997). Proxy measures elsewhere in European mountain regions also offer evidence of recent changes. For example:

- Borehole monitoring of permafrost temperatures showed that relief and aspect led to greater variability between Swiss and Italian Alpine

Figure 5.2 Annual precipitation series (left graph) and annual cloudiness series (right graph) for the northwest (NW) and southeast (SE) Alps



Note: All values relative to 1901–2000 averages. Single years (thin lines) and 10-year smoothed means (bold lines).

Source: ZAMG-HISTALP database (Auer *et al.*, 2007).

boreholes than between those in Scandinavia and Svalbard. However, 15 years of thermal data from the 58 m-deep Murtèl–Corvatsch permafrost borehole in Switzerland, drilled in ice-rich rock debris, showed an overall warming trend, with high-amplitude inter-annual fluctuations reflecting early winter snow cover fluctuations more strongly than air temperatures (Harris *et al.*, 2003).

- In upland lakes, spring temperature trends were highest in Finland; summer trends were weak everywhere; autumn trends were strongest in the west, in the Pyrenees and western Alps; while winter trends varied markedly, being high in the Pyrenees and Alps, low in Scotland and Norway and negative in Finland (Thompson *et al.*, 2009).

5.2.2 Climate change scenarios

A number of studies (Giorgi *et al.*, 1994; Beniston and Rebetez, 1996; Fyfe and Flato, 1999) suggest that the highest mountainous areas are expected to experience the most intense increases in temperature. If this occurs, the impact of climate warming could be enhanced due to the high dependence of surrounding regions on the water resources provided by the mountains (Beniston, 2003, 2006); this could be particularly important in river basins where snow and glaciers play a major part in regulating seasonal hydrological cycles (Barnett *et al.*, 2006); this is discussed further in Chapter 6.

Figure 5.3 presents predicted seasonal changes in precipitation and temperature in the Alps up to the end of the 21st century. By 2071–2100, summers in Europe's southern mountains are projected to warm by 5–6 °C (Räisänen *et al.*, 2004; Christensen and Christensen, 2007), in the Alps by up to 5 °C (Smiatek *et al.*, 2009; van der Linden and Mitchell, 2009; Box 5.2) and in the north by 3–5 °C. A similar latitudinal contrast is projected for 21st century precipitation, with northern mountains experiencing increases of 20–50 %, and decreases of ~ 25–50 % in southern ranges, associated with a north-eastward extension of the summer mean Atlantic subtropical high pressure system. In summer, most RCMs simulate a strong decrease in mean precipitation for the Alps (Frei *et al.*, 2003, 2006; Schmidli *et al.*, 2007; Smiatek *et al.*, 2009), a pattern also found for the Pyrenees (Lopez-Moreno *et al.*, 2008). One significant outcome may be an increased frequency of lightning fires (Box 5.3). Mean net shortwave length radiation is projected to increase by around 10 watts per square metre (W/m^2) over much of Europe during the summer (Lenderink *et al.*, 2007). Another climatic element strongly affected by circulation change is wind speed. In general, summer wind speeds are projected to decrease in southern Europe but to increase in the north (Räisänen *et al.*, 2004), as the Atlantic storm track shifts polewards (Bengtsson *et al.*, 2006).

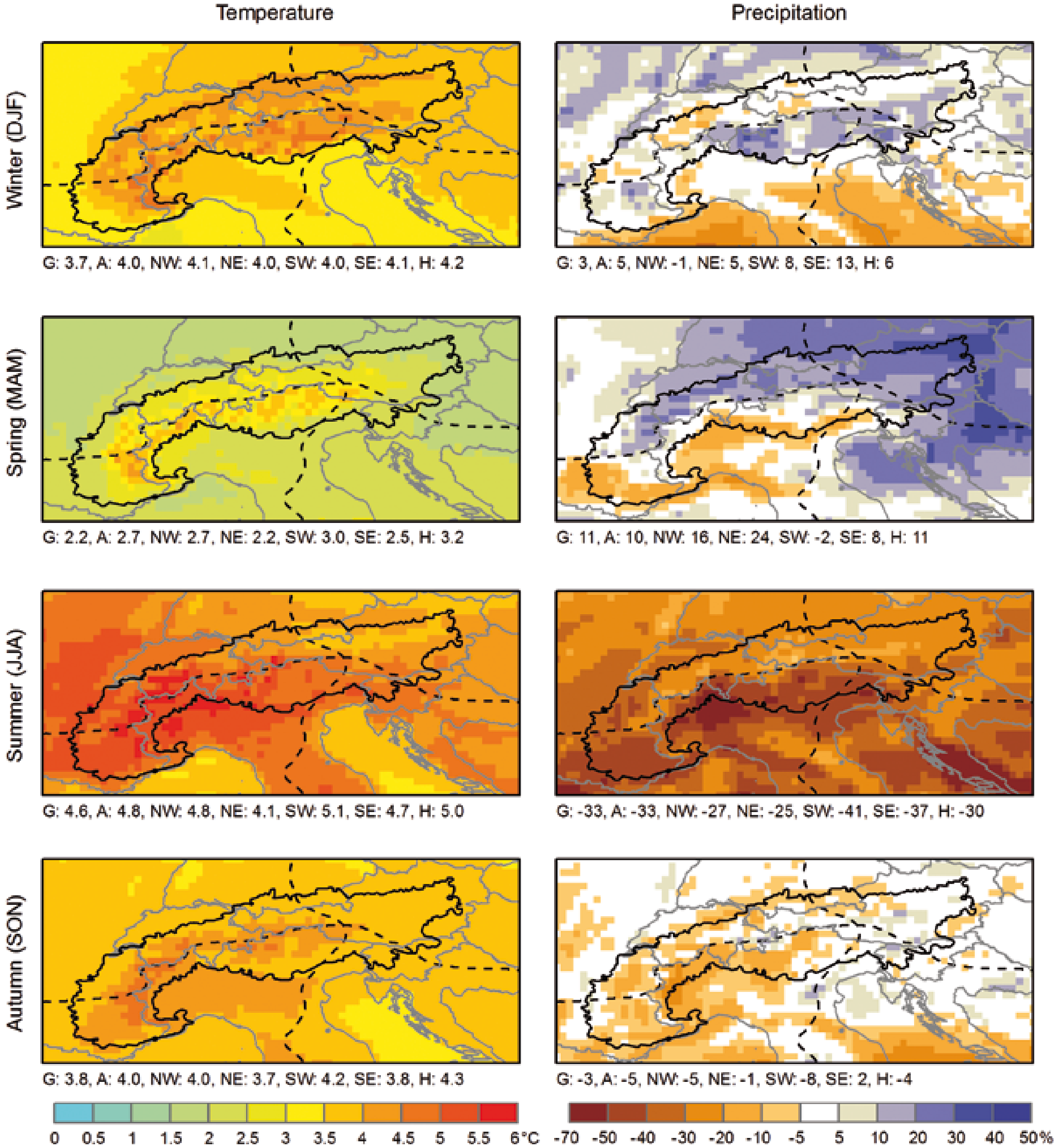
Winters are also projected to warm, with a geographically consistent pattern of 4–5 °C increases in mean winter temperature in Europe's eastern mountains, but increases of 1–3 °C in western, more maritime, settings (Christensen and Christensen, 2007; Räisänen *et al.*, 2004). All scenarios agree on a general increase in winter precipitation in northern and central Europe, and a decrease to the south of the Alps. However, large local changes in precipitation are projected for parts of Norway and the Alps, where the pronounced topography makes any change in precipitation pattern very sensitive to wind direction. A number of scenarios indicate a distinct wintertime increase in storm track density over the British Isles and across into Western Europe, but a decrease in the Mediterranean (Bengtsson *et al.*, 2006). However, while the basic dynamics governing shifts in the strength and path of the mid-latitude storm track are well understood, the ability of models to reproduce these is limited. As it is unclear which, if any, climate model is capable of satisfactory projections, there is considerable uncertainty about the future behaviour of storm tracks in the north-east Atlantic (Woolf and Coll, 2007).

5.2.3 Changes in snow cover and permafrost

Both temperature and precipitation increases to date have impacted mountain snowpacks simultaneously on a global scale. However, the nature of the impact is strongly dependent on geographic location, latitude, and elevation, among other factors (Stewart, 2009). In general, snow cover throughout the Alps decreased throughout the 20th century, in particular since the 1980s and during the latter part of the century (Stewart, 2009), and continues to do so (EEA, 2009).

Climate models suggest that future snowfall in the Alps could be reduced by 3 % in the winter, with altitudes above 1 500 m experiencing a loss of approximately 20 % up to the late 21st century (EEA, 2009); other results suggest that snow below 500 m could almost disappear completely (Jacob *et al.*, 2007). The duration of snow cover is expected to decrease by several weeks for each projected °C of temperature increase in the Alps, with the greatest sensitivity in the middle altitude bands (575–1 373 m) in winter and spring (Hantel *et al.*,

Figure 5.3 Seasonal changes in precipitation and temperature until the end of the 21st century, according to CLM Scenario A1B



Source: EEA, 2009.

2000; Wielke *et al.*, 2004; Martin and Etchevers, 2005). Keller *et al.* (2005) report an average decrease of a month in the modelled snowmelt for Alpine rock and sward habitats in response to a 4 °C increase in mean temperature. According to model projections following different greenhouse gas emission scenarios, the thickness and duration of snowpack in the Pyrenees will decrease dramatically over the next century, especially in the central and eastern areas of the Spanish Pyrenees (Lopez-Moreno *et al.*, 2008). The magnitude of these impacts will follow a marked altitudinal gradient. The maximum

Box 5.2 Future climate in the Greater Alpine Area

Over the past century, the mean temperature in the Alps increased by 1.1 °C. GCMs indicate that, by 2100, the temperature of the Alpine region, relative to the period 1980–1999, may increase by up to 5 °C (IPCC, 2007), and that summer precipitation will decrease significantly. Analysis of monthly mean values from six GCMs using the A1B emission scenario for the Greater Alpine Area for 2071–2100 showed increases in temperature of 3.4 °C in winter and 4.3 °C in summer relative to 1961–1990. On average, these models show that precipitation will increase by 10 % in winter and decrease by 30 % in summer (Smiatek *et al.*, 2009).

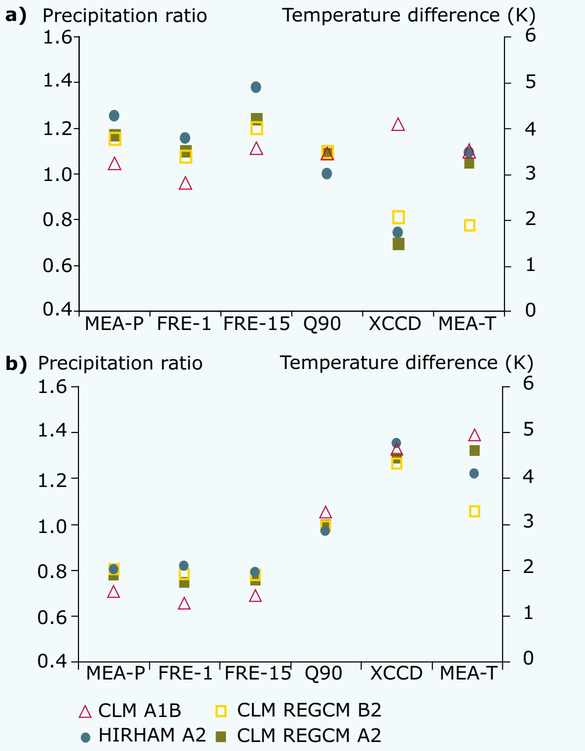
Several statistical and dynamic downscaling approaches have been applied to derive highly resolved climate change information for the Alpine region. While the regional models reproduce spatial precipitation patterns and the annual cycle in complex terrain, there are still large biases in precipitation when compared with observations. In the PRUDENCE project (Christensen and Christensen, 2007), an ensemble of 25 RCMs, mostly run with a horizontal resolution of 0.5 °C in a time slice experiment using the A2 scenario, showed a mean increase in the seasonal mean temperature in the Alps of 3.53 °C in winter and 5.04 °C in summer, compared to the 1961–1990 mean. The relative seasonal mean precipitation change was + 20 % in winter and – 26 % in summer. Schmidli *et al.* (2007) evaluated six statistical and three dynamical downscaling models, and found a strong decrease in mean precipitation for the entire Alpine region in summer for 2071–2100; a substantial reduction in the frequency of wet days in summer resulted in a large increase (50–100 %) in the maximum length of dry spells. Most models also simulate an increase in precipitation intensity on wet days in summer and in the 90 % quantile of precipitation on wet days in winter, compared to 1961–1990. Some models indicate increased precipitation intensity in summer, despite the strong decrease in mean precipitation.

Figure 5.4 shows the simulated changes in temperature and various precipitation statistics as simulated by two RCMs — HIRHAM (Christensen and Christensen, 2007) and RegCM (Gao *et al.*, 2006) — driven with boundary forcings from the HadAM3 GCM, and also the transient CCLM (Rockel *et al.*, 2008) RCM, driven with boundary data from the ECHAM5 GCM as evaluated by Smiatek *et al.* (2009). For the Alpine region, the RCM models simulate a winter temperature increase for 2071–2100 of 2 °C to over 3 °C and, in summer, of almost 5 °C compared to 1960–1990. Summer precipitation decreased up to 29 %, with a substantial increase in the maximum length of dry spells. For winter, all models indicate a precipitation increase, with more wet days and strong precipitation events. In particular regions, however, the RCMs simulate much greater differences: an increase of more than 30 % in winter and a decrease of almost 40 % in summer.

The analysis of the regional climate simulations shows that results based on different regional models, different driving global models, and different emission scenarios show similar trends — but that these differ in the magnitude of the expected climate change signal. Nevertheless, there are still large biases in the reproduction of the current climate, and therefore substantial uncertainties in the magnitude of expected climate change.

Source: Gerhard Smiatek and Harald Kunstmann (Institute for Meteorology and Climate Research, Karlsruhe Institute of Technology, Germany).

Figure 5.4 Simulated change in precipitation (2071–2100 to 1961–1990) and temperature (2071–2100 to 1961–1990) statistics in the Greater Alpine Area in (a) winter and (b) summer for four Regional Climate Models



Note: Statistics: MEAP: mean climatological precipitation, FRE-1: frequency (ratio) of wet-days with precipitation > 1 mm, FRE-15: frequency (ratio) of days with precipitation > 15 mm, Q90: 90 % quantile of the distribution function on wet days, XCCD: maximum number of consecutive dry days, MEA-T: mean climatological temperature.

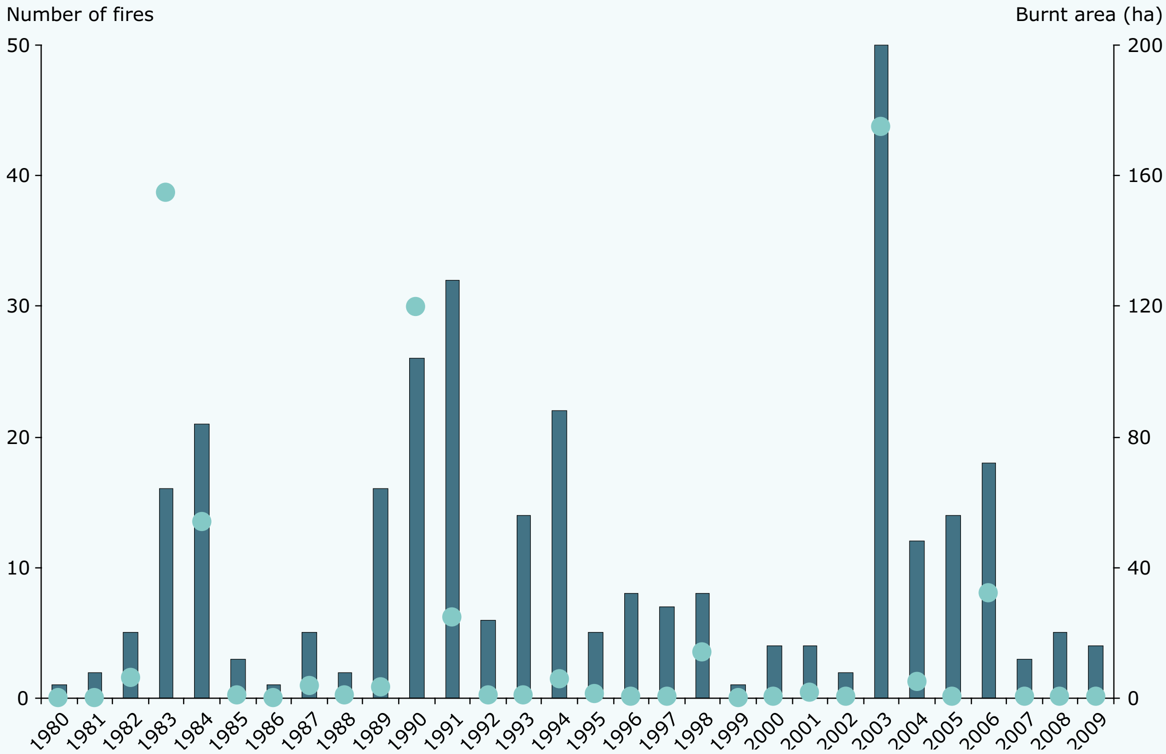
Box 5.3 Lightning-induced fires in the Alpine region

In most forest ecosystems, lightning is the only natural source of ignition (Pyne *et al.*, 1996). As well as factors such as fuel (type, moisture, density and depth) and topography, the frequency and distribution of lightning-caused forest fires greatly depend on weather (drought or lack of precipitation, frequency and type of the thunderstorms and of the associated lightning discharges, and ventilation). This makes lightning-fires of particular relevance for assessing the possible impact of climate change (Street, 1989; Flannigan and van Wagner, 1991; Balling *et al.*, 1992; Weber and Stocks, 1998).

In Europe, most lightning-induced forest fires take place in the southern boreal forests of Fennoscandia (Granström, 1993; Larjavaara *et al.*, 2005) and in the mountain regions from the Iberian Peninsula (Vasquez and Moreno, 1998; Galán *et al.*, 2002) to the Western and Central Alps (Conedera *et al.*, 2006). Lightning-caused forest fires may occur between May and October, but most events (90 % or more) take place during the warm summer months of June to August, with some differences due to the different elevation, expositions and start of the warm season (Granström, 1993; Wotton and Martell, 2005; Conedera *et al.*, 2006). In general, lightning causes fires in coniferous forests located on steep slopes at high elevations. Such fires are often started by an underground ignition that may keep smouldering locally for days and weeks resulting in small-size burned areas (Conedera *et al.*, 2006).

Given their natural origin, the frequency and extent of lightning-ignited fires depend strongly on seasonal weather conditions; data for the southern slope of the Swiss Alps show an increase with drought indices. In the Swiss Alps, the inter-annual variability in fire frequency and burnt area is high, with no clear increasing trend (Figure 5.5).

Figure 5.5 Annual variability in lightning-induced fire frequency (dots) and burnt area (bars) in the Swiss Alps



Source: Swissfire database.

Box 5.3 Lightning-induced fires in the Alpine region (cont.)

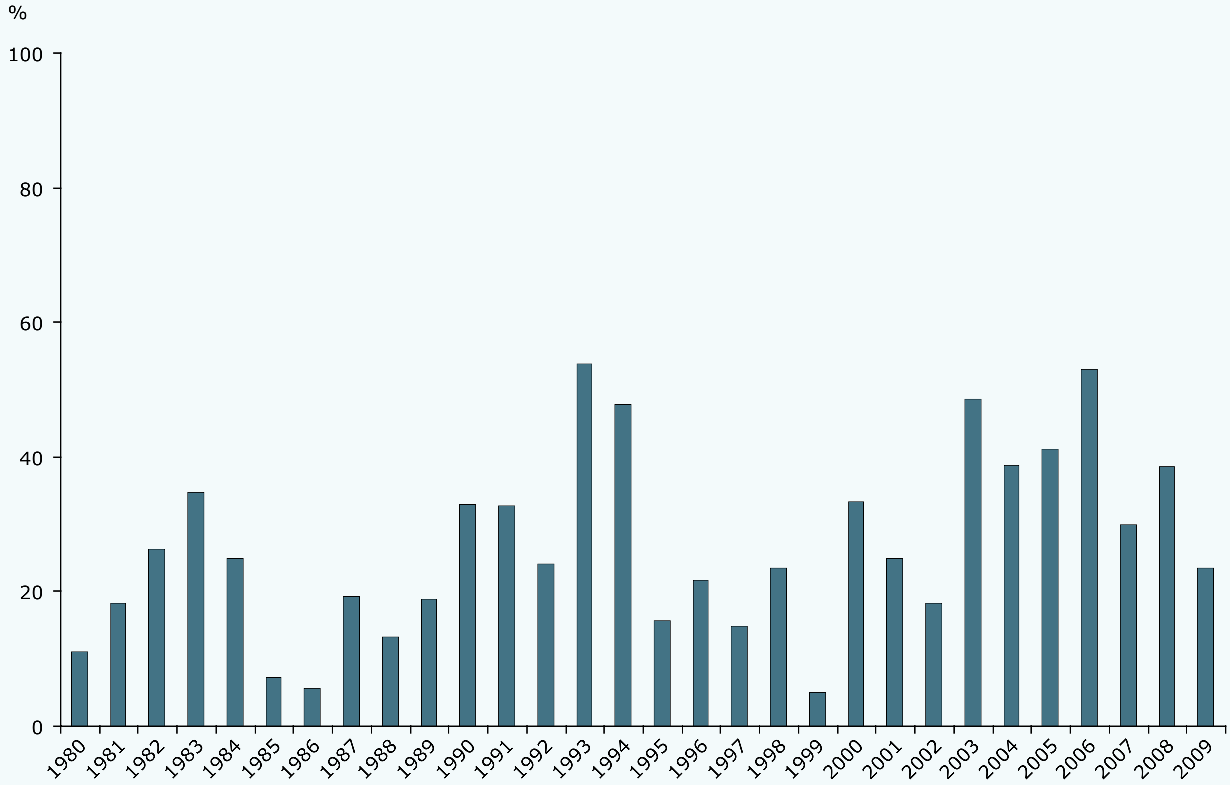
The relative importance of lightning-caused fires, however, increased in recent decades (Figure 5.6). In the period from May to October, the proportion of lightning fires changed from an average of 20.3 % in the 1980s to 29.1 % in the 1990s, and 41.1 % in the 2000s (Figure 5.6), highlighting the difficulty of preventing the ignition of fires of natural origin. In addition, in drought-summer years such as 1983–1984, 1990 and 2003, lightning fires are more likely to turn from underground into surface or crown fires, causing a significant increase in the burned area (Figure 5.5).

From a management point of view, lightning-induced fires occur mostly in remote locations and burn underground (Conedera *et al.*, 2006), making detection and suppression activities more difficult. When intense lightning activity occurs following a drought, lightning-ignited fires aggregate in both time and space, which may put a strain on the initial attack by the fire brigades and thus lead to longer and more difficult fire fighting campaigns (Podur *et al.*, 2003; Wotton and Martell, 2005).

As climate change may lead to an increased frequency of hot and dry summers (Schär *et al.*, 2004), these results suggest that, in the future, lightning-induced fires may assume a significant ecological role and have a higher economic impact in the Alps, as suggested by Schumacher (2004).

Source: Marco Conedera and Gianni Boris Pezzatti (Swiss Federal Research Institute, Switzerland).

Figure 5.6 Yearly relative frequency of lightning-induced fires with respect to total number of fires in the summer period (June to September) in the Swiss Alps



Source: Swissfire database.

accumulated snow water equivalent may decrease by up to 78 %, and the season with snow cover may be reduced by up to 70 % at 1 500 m (Lopez-Moreno *et al.*, 2009). However, the magnitude of the impacts decreases rapidly with increasing altitude, with snowpack characteristics projected to remain largely similar in the highest sectors (Lopez-Moreno *et al.*, 2009). Stewart (2009) summarises work examining observed and projected changes in snow cover and snowmelt-derived streamflow for the European Alps and European mid-elevation mountain ranges.

The lower elevation of permafrost is likely to rise by several hundred metres. Rising temperatures and melting permafrost will destabilise mountain walls and increase the frequency of rock falls, threatening mountain valleys (Gruber *et al.*, 2004; Harris *et al.*, 2009; Keiler *et al.*, 2010). In northern Europe, lowland permafrost will eventually disappear (Haeberli and Burns, 2002). Changes in snowpack and glacial extent (Box 6.2) may also alter the likelihood of snow and ice avalanches, depending on the complex interactions of surface geometry, precipitation and temperature (Martin *et al.*, 2001; Haeberli and Burns, 2002).

5.3 Research needs

5.3.1 Instrumental data and monitoring networks

Although some climatic information for mountain regions can be obtained from radiosonde measurements, significant differences between radiosonde and mountain surface data have been observed (e.g. Seidel and Free, 2003). This emphasises the need for paired station monitoring networks at lowland and mountain locations (Barry, 2008) and, while there have been encouraging developments in expanding the instrumental data provision for the Alps, an expanded monitoring network across Europe's mountain regions is needed (Schär and Frei, 2005; Bjornsen Gurung *et al.*, 2009; Smiatek *et al.*, 2009). This scarcity of instrumental data in many mountainous regions also hampers the performance assessment of outputs from this and subsequent generations of RCMs; measures to address these data gaps could include the incorporation of more mountain areas in the integrated monitoring and observation system mooted for Europe (EEA, 2008).

5.3.2 Sources of uncertainty in climate change projections

Projections of climate change are subject to a high degree of uncertainty (Jones, 2000), as a consequence of both aleatory ('unknowable' knowledge) and epistemic ('incomplete' knowledge) uncertainty (Hulme and Carter, 1999; Oberkampf *et al.*, 2002; Foley, 2010); at least some of which relates to knowledge gaps in the understanding of the climate system (Albritton *et al.*, 2001; EEA, 2008). Adding to these, the accuracy of GCM performance in areas of complex terrain and the subsequent cascade through RCMs introduces a further tier of uncertainty.

5.3.3 Climate modelling challenges

Even with the evolution of ever more complex and sophisticated GCMs, issues remain concerning their robustness (Chase *et al.*, 2004), and their reproduction of the detail of regional climates remains limited (Zorita and von Storch, 1999; Gonzalez-Rouco *et al.*, 2000; Jones and Reid, 2001; Bonsal and Prowse, 2006; Connolley and Bracegirdle, 2007; Perkins and Pitman, 2009). For regions of heterogeneous terrain, such as mountains, RCMs provide more credible information on changes in climates than GCMs. However, since each RCM is constrained by the boundary conditions of the GCM used to drive it, uncertainties in GCM predictions are effectively cascaded (Carter and Hulme, 1999; Frei *et al.*, 2003; Jenkins and Lowe, 2003; Saelthun and Barkved, 2003; Déqué *et al.*, 2007; Jacob *et al.*, 2007).

An additional limitation of using RCM outputs in mountain regions relates to the fact that the true roughness of mountain terrain is represented by a smoothed surface in models. Consequently, the elevation of specific sites is poorly represented and the observed climate is not accurately reproduced (Coll *et al.*, 2005; Engen-Skaugen, 2007; Beldring *et al.*, 2008). Overall therefore, local controls on climate in mountain regions are not adequately captured by current GCMs and RCMs, and the best resolution of 50 x 50 km remains inadequate for impact assessment (EEA, 2008), particularly in mountainous areas. Finally, for both GCMs and RCMs, even if models improve in performance in simulating current climate, this may not be a reliable indicator of their performance for predicting future climate.

6 The water towers of Europe

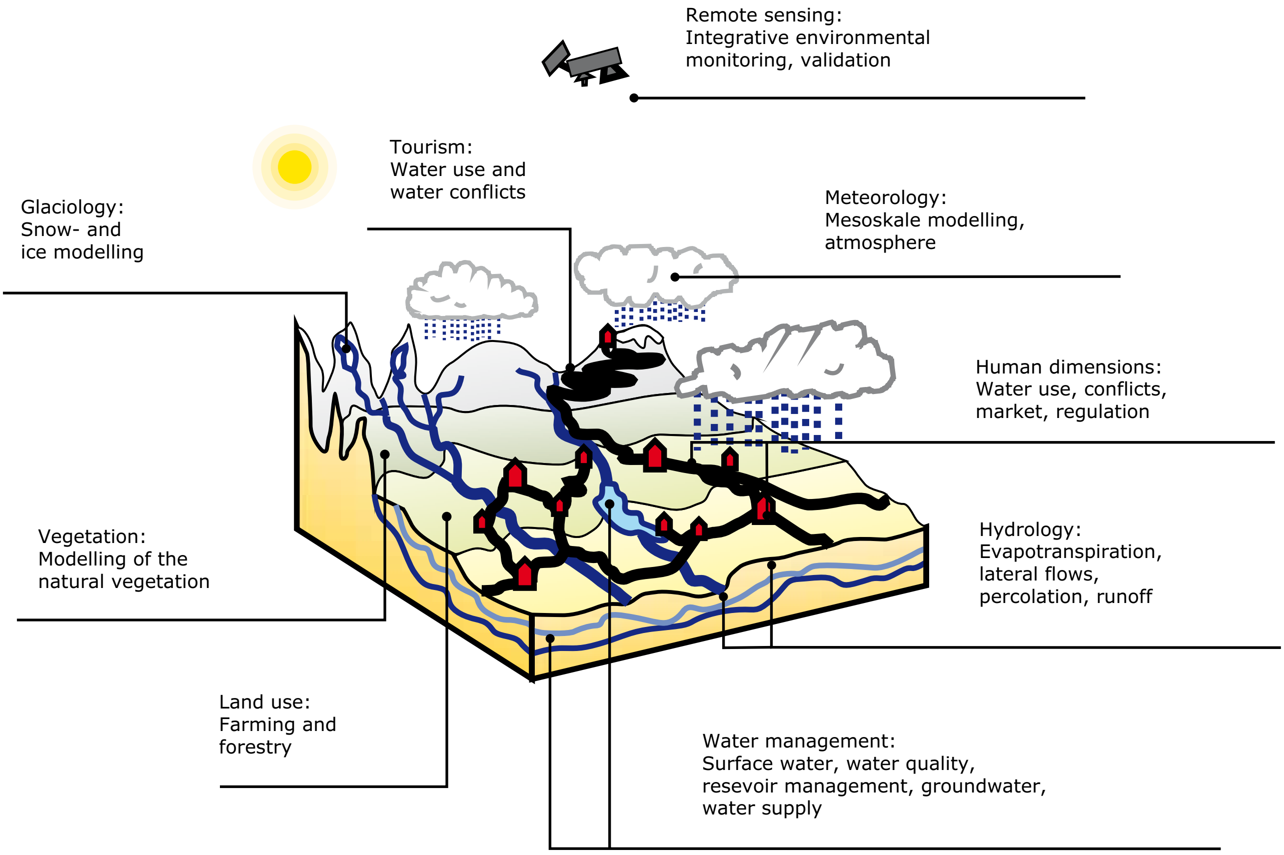
Mountains are the 'water towers' of Europe. They provide both vital sources of fresh water and areas for its accumulation and storage in the form of rivers, lakes, reservoirs, glaciers and seasonal ice or snow. Water originating from the mountains is an essential natural resource (Figure 6.1) for a number of economic, environmental and social reasons: for the production of hydropower; for businesses and livelihoods within mountain regions and within adjacent lowlands; and for their valuable ecosystems. Consequently, not only the quantity but also the quality of mountain water is important.

Hydrological systems in mountain areas are also under threat from climate change, which may alter patterns of precipitation, snow cover (Chapter 5) and glacier formation, with further effects downstream. Broad projections include more frequent droughts in summer, floods and landslides in winter, and higher inter-annual variability of precipitation (EEA, 2009a). Climate change will therefore have significant impacts on the availability of mountain water in terms of both total seasonal flows and water quality.

6.1 Water towers — mountain hydrology

The term 'water tower', in the context of hydrology, signifies an elevated area of land that supplies disproportional runoff in comparison to the adjacent

Figure 6.1 Various dimensions of mountain and water use, modelling and management

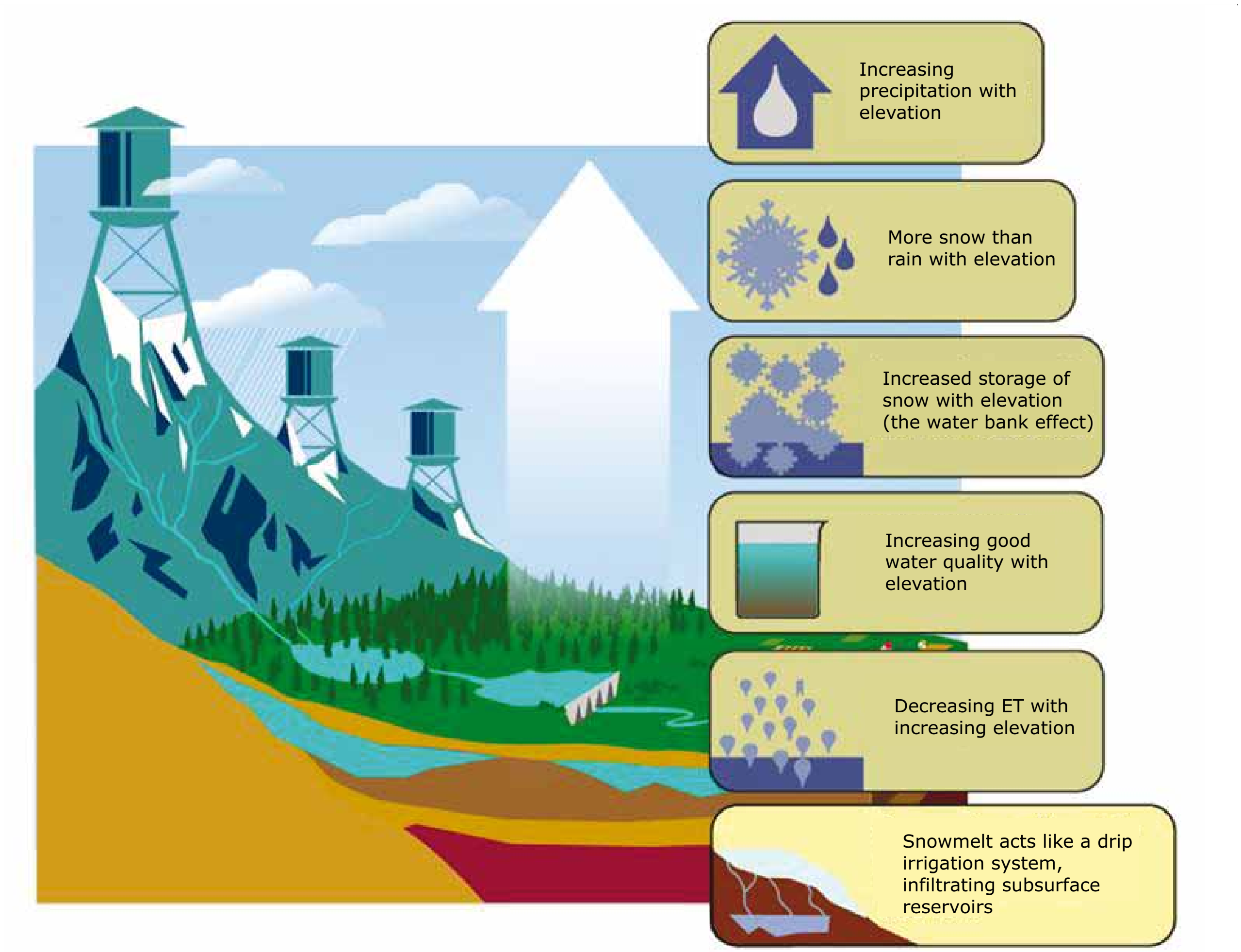


Source: Glowa_Danube www.glowa-danube.de/frameset.htm.

lowland areas (Viviroli *et al*., 2007). The phrase conveys the importance of a particular mountain area for the capture, retention, distribution and discharge of freshwater and the multiple functions it supports, including its utilisation in the surrounding lowlands (Figure 6.2). In Europe, water is generally provided by mountains at a time when precipitation and runoff are limited in the lowlands, and water demands are at their highest, especially during the typically low precipitation period of late summer. Mountains therefore 'play a distinct supportive role with regard to overall discharge and their natural storage mechanism benefits many river systems throughout Europe' (EEA 2009a, p. 30). The concept of a water tower is, however, relative, as the extent of disproportionality also depends on the location of a mountain and the functions it provides (Viviroli *et al*., 2007).

Mountain climates are governed by four major geographical factors: continentality, latitude, altitude and topography (Barry, 2008). Europe's mountains vary greatly in all of these factors, as noted in Chapters 1 and 5. The average river flow within Europe is 450 mm per year, ranging from 50 mm per year in arid areas such as southern Spain to over 1 500 mm in areas facing the Atlantic and in the Alps (EEA, 2009b). The Alps, for example, provide a disproportionately high contribution to the total discharge of four major rivers: the Danube, Rhine, Po and Rhone (Figure 6.4 and Table 6.1) which flow from the region (Weingartner *et al*., 2007). Box 6.1 provides further detail on the hydrology of four major European mountain regions, and Box 6.2 provides further detail on glaciers, which are vital elements of the water cycle, especially in the Alps and the Scandes.

Figure 6.2 Conceptual diagram of a water tower



Source: www.icpdr.org/icpdr-files/14181.

Box 6.1 The hydrology of four major European mountain regions

The Alps

The Alps are located in an area of extremely high humidity owing to their close proximity to the northern and western Atlantic Ocean, to the Mediterranean sea to the south, and due to the influence of predominantly westerly winds. Their hydrological importance is also due to the considerable amounts of meltwater from snow and ice originating from them during the summer months (Viviroli and Weingartner, 2004). Almost two-thirds of the Central European perennial surface ice cover is located in the Alps, with the Aletsch Glacier being the largest valley glacier (Box 6.2). Many large and well-known European lakes are located in the Alps including Lake Constance, Lac Leman (Lake Geneva) and Lago Maggiore.

Most of Europe's major rivers have their headwaters in the Alps and their discharge is transported via river systems to lower-lying areas. Hence, the water system of the Alps is very important not only for the countries of this mountain range but also for large parts of Europe (EEA, 2009a). The four main rivers draining the Alps (Rhine, Rhône, Po and upper Danube) contribute a remarkably high amount of water (Table 6.1), supplying up to 2–6 times more water than might be expected on the basis of catchment size alone (Viviroli and Weingartner, 2004). The importance of the Alps in relation to water resources is primarily based on enhanced precipitation as rainfall generally increases with altitude. A large proportion of the precipitation falls as snow at higher altitudes, and may form glaciers, which are key features of the hydrology of the Alps. Lower temperatures, shorter growth seasons and more shallow soils at higher elevations also result in lower evapo-transpiration rates, causing a positive water balance in the mountains. The Alpine rivers vary significantly in annual mean discharge per area, partly due to the positions of the monitoring stations, but mostly because of climatic conditions and water usage (EEA, 2009a). In the future, the combined effects of droughts and increased water consumption in the Alps could cause water supply problems throughout Europe. Future climate change is projected to lead to a shift from summer precipitation to winter precipitation and — together with an earlier and reduced snow melt due to lower storage of winter precipitation as snow, as well as less glacial melt water — will lead to an essential decrease in summer run-off all over the Alps (EEA, 2009a).

Pyrenees

The Pyrenees are the water towers for southwest France and northern Spain, particularly the basins of the Ebro and Garonne. The western and central part of the range receives a much greater amount of precipitation than the eastern part, due to moisture-laden air coming from the Bay of Biscay. The region is typically divided into three climatic zones: the Atlantic (or Western); the Central; and the Eastern Pyrenees. Precipitation falls predominantly during winter in areas adjacent to the Atlantic, and during spring and autumn in the Mediterranean regions, with extensive and thick snow cover from December to April in areas over 1 500 m above mean sea level, with a longer duration of snow cover at higher altitudes and in shaded areas (García-Ruiz *et al.*, 1986; López-Moreno and Nogués-Bravo, 2005). Snow melt is vital for the ecological and socio-economic well-being of the region and is a major contributor to the amount of runoff and its seasonal distribution, playing a leading role within Pyrenean river basin water management in the semi-arid and highly populated Ebro valley (López-Moreno and García-Ruiz 2004; López and Justribó, 2010). The Ebro River receives 50–60 % of its discharge from the Pyrenees, although only 30 % of its catchment is in the mountains (López and Justribó, 2010). There are currently 41 glaciers in the Pyrenees, all centrally-located within one 100 km stretch of the range and covering a total area of approximately 8.1 km^2 (Serrat and Ventura, 1993). These glaciers are small: the largest, Glaciar de Aneto, is only 1.32 km^2, while half are 0.1 km^2 or less in area. All glaciated peaks are higher than 3 000 m — but not all peaks that reach this height have glaciers — and, unlike the glaciers in the Alps, they do not descend far down into the valleys (Serrat and Ventura, 1993). The melting of glaciers in the Pyrenees is much more advanced than in the Alps (Box 6.2). In contrast to the Alps, there are no very large lakes in the region. However, there are numerous smaller lakes, such as those in the Aigüestortes in the Alta Ribagorza region.

Scandinavian mountains

The distance from the top of the Scandes range to the ocean is greatest on the Swedish side, where a dozen roughly parallel drainages run from the mountains into the Gulf of Bothnia. Most of the rivers at the northern end of the range are above the Arctic Circle, while those at the southern end flow into the ocean at about 60 °N. The region does not have large topographic relief, but the rivers have a number of steep rapids interspersed with lower-gradient segments. Mean annual precipitation is 500–1 000 mm, much of which falls as snow. The timing and level of runoff is variable and dependent on river location: the northern rivers have low winter flows with rapid snowmelt and intense flooding during spring to early summer; rivers draining into the central eastern coastal area have less intense spring floods; while rivers in the far south

Box 6.1 The hydrology of four major European mountain regions (cont.)

have a more even annual discharge pattern (Nilsson, 1999; Wohl, 2006, p. 225–226). The last Norwegian glacier inventory of 1988 recorded 1 627 glaciers covering a total area of 2 609 km², with an estimated volume of 164 km³ (Nesje *et al.*, 2008). Since 2000, all observed glaciers have experienced a mass deficit, with an annual frontal retreat of over 100 m mainly due to high summer temperatures (Andréassen *et al.*, 2005; Nesje *et al.*, 2008). In Norway, 15 % of utilised runoff originates from glacier basins and 98 % of their electricity is generated by hydropower (Andréassen *et al.*, 2005).

Carpathians

The headwaters of several major rivers originate in the Carpathians. Most of the range is located in the middle and the lower parts of the Danube River Basin, with the remainder in the Dniester, Vistula and Oder basins. North of Vienna, the Outer Carpathian Depressions are drained by the upper courses of the Morava and Odra rivers. Approximately 90 % of the rivers which drain from the Carpathians flow into the Black Sea. Many, such as the Vah, Tisza and its tributaries lie within the Danube River Basin. To the east, the main river flowing into the Black Sea is the Dniester, while the northerly rivers — the Vistula and Oder — flow into the Baltic Sea. Numerous lakes are situated in cirques and glacial valleys within the high mountain zone. The largest glacial lakes are in the North-western Carpathians, where Quaternary glaciers were most prominent. The Eastern and Southern Carpathians contain over 200 glacial lakes, mostly in the Retezat (Bucura, Zănoaga) and Făgăraş Mountains. Many water storage reservoirs are found on rivers, such as the Bistriţa, Argeş and Olt in Romania, the San in Poland and the Osana in Slovakia; the largest on the Danube is the Iron Gate Dam between Romania and Serbia (UNEP, 2007a). Pressure to develop the Carpathians has increased during the last two decades giving rise to a number of key environmental concerns which include harmful mining technologies and the development of the agricultural sector without further impacts (WWF, 2008).

Source: Sue Baggett (Independent Consultant, the United Kingdom).

Box 6.2 The uncertain future of European glaciers

Glacier observations have been internationally coordinated since 1894. Despite its limitations, the compilation and free exchange of standardised glacier information for more than a century constitutes an invaluable treasure of global environmental monitoring and a key element with respect to scientific knowledge and public awareness of climate change. In the first decades, reported observations primarily concerned changes in glacier length as well as a few pioneer studies of glacier accumulation and melt at individual points. In the 1940s, glacier mass balance measurements were initiated. The extraordinary density and continuity of data about changes of glaciers in the Alps and Scandinavia thus constituted the backbone of the international glacier monitoring during its historical development (Haeberli, 1998). Glacier inventories based on aerial photographs and satellite images, together with digital terrain information, have opened new perspectives for documenting the distribution and ongoing changes of glaciers and ice caps. Computer models combining data from observed time series with glacier inventory information make it possible to look at changes of large numbers of glaciers over entire mountain regions. Information on glacier changes is available from regularly issued reports (WGMS 2008a; WGMS 2009; and earlier volumes). Standardised data on glacier changes and distribution are available through the Global Terrestrial Network for Glaciers (www.gtn-g.org). Recent overviews are provided by Haeberli *et al.* (2007), UNEP (2007b), WGMS (2008b), and Zemp *et al.* (2009).

Glacier distribution and available datasets in Europe

In the second half of the 20th century, European glaciers and ice caps with a total surface area of approximately 6 000 km² existed in Scandinavia (about 3 000 km²), the Alps (slightly less than 3 000 km²), and the Pyrenees (12 km²) (WGMS, 1989). A few small glaciers and glacierets are also found in, for example, the Apennines and the mountains of Slovenia, Poland and Albania. Locations of long-term mass balance observations are shown in Map 6.1.

Box 6.2 The uncertain future of European glaciers (cont.)

Most of the ice on the Scandinavian Peninsula is in southern Norway, with some glaciers and ice caps in northern Norway and the Swedish Kebnekaise mountains. Annual front variation measurements began in Norway and Sweden in the late 19th century. Several glaciers have been observed on a regular basis for over a century; over 60 Scandinavian front variation series are available. Storglaciären in Sweden (see photo later in this box) provides the longest existing mass balance record for an entire glacier, with continuous seasonal measurements since 1946. Mass balance measurements in Norway started at Storbreen (Jotunheimen) in 1949. Overall mass balance measurements have been reported from 39 glaciers, with eight continuous series since 1970.

The densely populated Alps, in which the Grosser Aletschgletscher is the longest, have the greatest number of length change and mass balance measurements, with many long-term data series. Annual observations of glacier front variations started in the second half of the 19th century in Austria, Switzerland, France, and Italy; there are now more than 680 data series, distributed over the entire Alpine mountain range. Mass balance measurements started in 1949; corresponding data are available for 43 glaciers, with 10 continuous series since 1968.

Some smaller glaciers are found in the Maladeta massif of the Pyrenees. There are two glaciers in the Pyrenees with length change data, one starting in the 1980s and a second one covering the 20th century, though with a few observation points. Mass balance measurements started in 1992 on the Maladeta Glacier.

European glacier changes — past and future

Scandinavian glaciers and ice caps probably disappeared in the early/mid Holocéne, approximately 10 000 years ago (Nesje *et al.*, 2008) and then reformed, with most reaching their maximum extent in the mid-18th century (Grove, 2004). Subsequently, following minor retreat with small frontal oscillations until the late 19th century, these glaciers experienced a general recession during the 20th century with intermittent periods of re-advances around 1910 and 1930, in the second half of the 1970s, and around 1990; the last advance stopped at the beginning of the 21st century (Dowdeswell *et al.*, 1997; Hagen *et al.*, 2003; Grove, 2004; Andréassen *et al.*, 2005) (Figure 6.3). Since 2001, all monitored glaciers have experienced a distinct mass deficit. With a scenario of a 2.3 °C summer temperature increase and a 16 % winter precipitation increase, 98 % of the Norwegian glaciers could disappear by the year 2100, involving a 34 % decrease in total glacier surface area (Nesje *et al.* 2008).

In the Alps, most glaciers reached their Little Ice Age (LIA) maximum towards the mid-19th century (Gross, 1987; Maisch *et al.*, 2000; Grove, 2004). Front variations show a general trend of retreat over the past 150 years with intermittent re-advances in the 1890s, 1920s, and 1970s–1980s (Patzelt, 1985; Pelfini and Smiraglia, 1988; Zemp *et al.*, 2007). The Alpine glacier cover is estimated to have diminished by about 35 % from 1850 to the 1970s, and another 22 % by 2000 (Paul *et al.*, 2004; Zemp *et al.*, 2007). Mass balance measurements show accelerated ice loss after 1980 (Vincent, 2002; Huss *et al.* 2008) culminating in an annual loss of 5–10 % of the remaining ice volume in the extraordinarily warm year of 2003 (Zemp *et al.*, 2005). Combining data from mass balance studies and glacier inventories with digital terrain information and climate scenarios from ensemble calculations with regional climate models (RCMs) shows that 75 % of the glacier area still existing in 1970–1990 is likely to disappear if summer air temperature increases by 2.5 °C (Zemp *et al.*, 2006). This loss appears to be almost independent of the scenario range in precipitation changes and might become reality during the first half the 21st Century (OcCC, 2007).

In the Pyrenees, the LIA maximum extent of most glaciers was around the mid 19th century (Grove, 2004). Since then, about two-thirds of the ice cover was lost in the Pyrenees, with a marked glacier shrinking after 1980 (Chueca *et al.*, 2005).

Perspectives on impacts

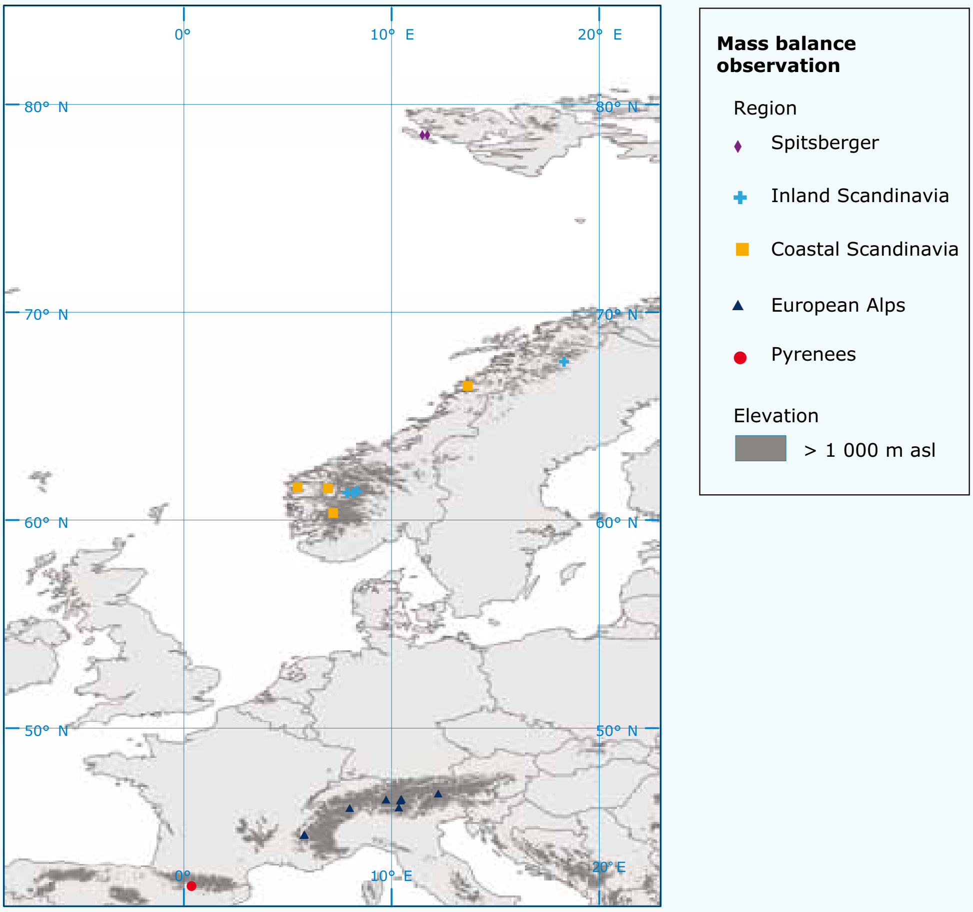
As their glaciers vanish, European mountains lose a strong symbol of intact human-environment relations and a particular attractiveness for tourism. The recent retreat has often been associated with an increase in debris cover and glacier lake development. Such new lakes are fascinating, constitute an interesting new potential for hydropower production, and replace some of the landscape attractiveness lost as glaciers disappear. However, they constitute a growing hazard for flood waves and far-reaching debris flows caused by moraine breaching or by rockfall from deglaciated slopes or slopes containing degrading permafrost (Haeberli and Hohmann 2008; Frey *et al.*, 2010).

Box 6.2 The uncertain future of European glaciers (cont.)

As a consequence, remedial actions have been needed at several locations in the Alps. Hydropower production from high-altitude reservoirs, of growing importance for covering short-term peak demands in the expanding European network, will also have to be fundamentally re-thought, with a view to storing more water in winter, and releasing it in summer — the opposite of current practice.

The most serious impact of vanishing mountain glaciers undoubtedly concerns the water cycle. The seasonality of runoff is likely to strongly change due to the combined effects of less snow storage in winter, earlier snowmelt in spring, and decreasing glacier melt. The lack of water during extended future droughts caused by changing snow and ice cover in high mountain ranges has the potential to seriously affect economies and livelihoods in general. Problems during the warm or dry season include decreased resources on the supply side, with longer-lasting discharge minima and low flow periods in rivers, lower lake and groundwater levels, higher water temperatures, perturbed aquatic systems and less power production, as well as increasing needs on the demand side, for water for a growing population, urbanisation, industrialisation, irrigation, power production and fire fighting (e.g. Middelkoop *et al.*, 2001; Watson and Haeberli, 2004; OcCC 2007).

Map 6.1 Glacier distribution in Europe



Note: The map shows the distribution of glaciers and ice caps as well as the locations of the available long-term mass balance observations labeled according to their region. These are Austre Brøggerbreen (NO) and Midtre Lovénbreen (NO) for Spitsbergen; Gråsubreen (NO), Hellstugubreen (NO), Storbreen (NO) and Storglaciären (SE) for Inland Scandinavia; Ålfotbreen (NO), Engabreen (NO), Hardangerjøkulen (NO) and Nigardsbreen (NO) for Coastal Scandinavia; Hintereisferner (AT), Kesselwandferner (AT), Sonnblickkees (AT), Gries (CH), Silvretta (CH), Saint Sorlin (FR), Sarennes (FR) and Caresèr (IT) for the European Alps; and Maladeta (ES) for the Pyrenees.

Source: Glacier data from WGMS, boundaries of glaciers and countries from ESRI data and maps, elevation data from GTOPO30 by US Geological Survey.

Box 6.2 The uncertain future of European glaciers (cont.)

The combined effect of lower water supplies and increasing demands holds a potential for conflict. Together with higher air temperatures, increased evaporation and changing snow conditions, the vanishing of mountain glaciers could dramatically sharpen fundamentally important questions: who owns water and who will decide on the priorities of its use?

Source: Wilfried Haeberli and Michael Zemp (Geography Department, University of Zurich, Switzerland).

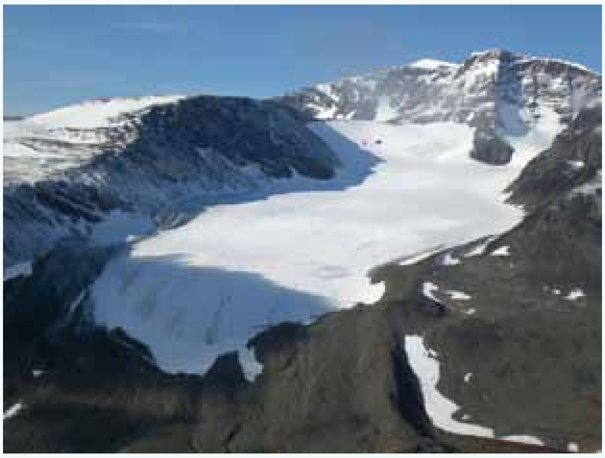
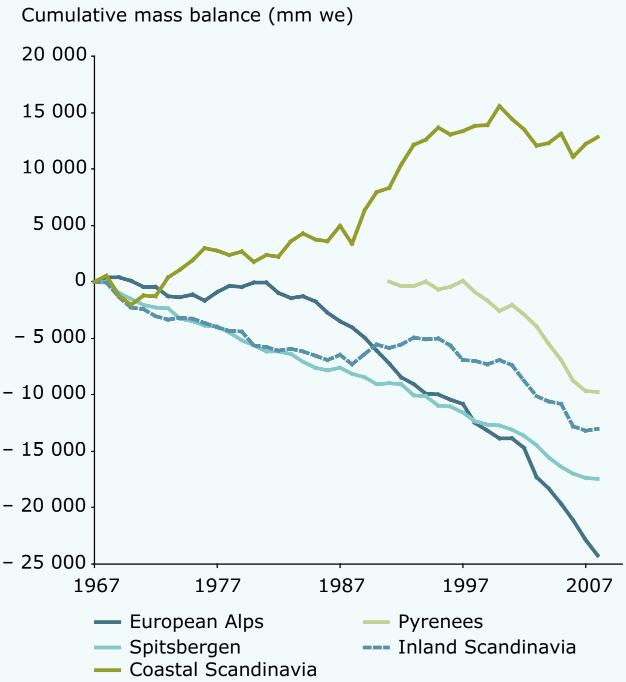


Photo: © T. Koblet, University of Zurich
Storglaciären, Sweden (September 2008).

Figure 6.3 Glacier mass balance of European regions, 1967–2008



Note: The figure shows cumulative mass balance of long-term monitoring programs averaged for the six European regions. The corresponding glaciers and regions are shown in Map 6.1.

Source: Glacier data from WGMS.

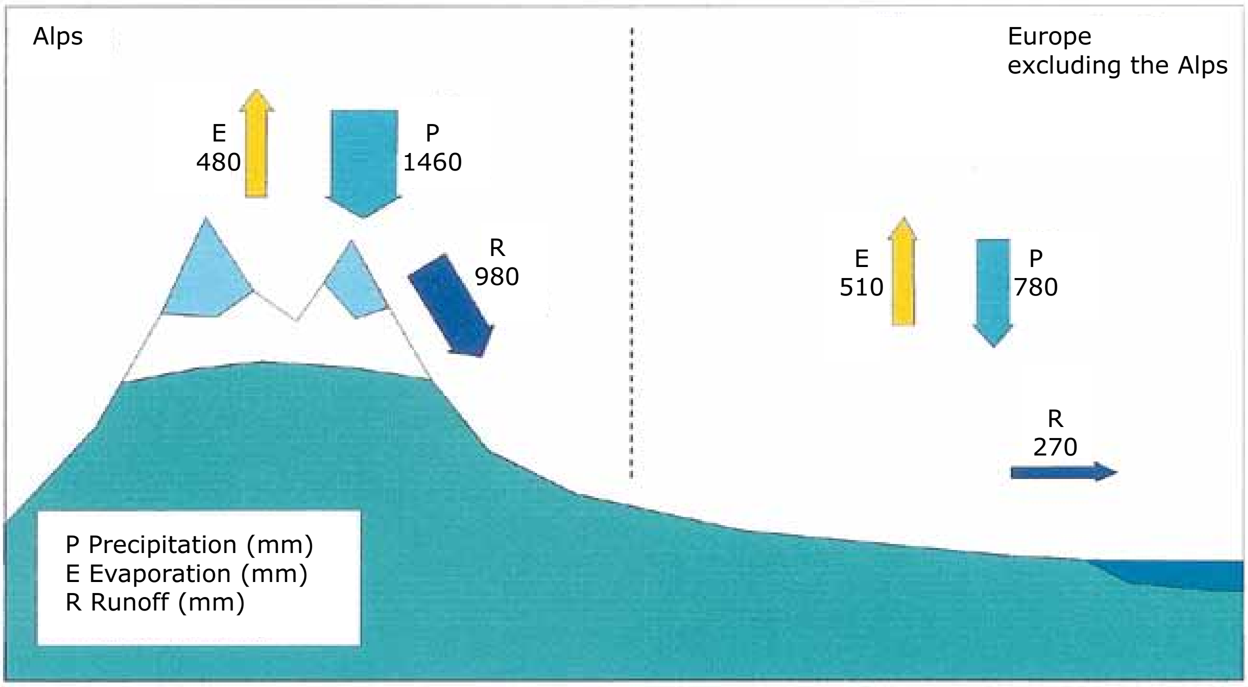
6.1.1 Water use in mountain regions and lowlands

Mountain water is a vital resource for a number of economic, environmental and social reasons, both within mountain areas and downstream. It supports and provides ecosystem services to the following sectors (EEA, 2009a):

- *Agriculture*
  The agricultural sector is one of the main water users in Europe, using 24 % of the total abstracted water from 1997 to 2005 (EEA, 2009a). Irrigation is concentrated in southern Europe (EEA, 2009a) with some countries growing water-intensive crops. Cotton growing in Greece, for example, requires 20 000 litres of flood water per kilogram of harvested product; in Andalusia, Spain, nearly 300 000 ha of land used for olive production are irrigated in the Guadalquivir river basin (EEA, 2009b). Most of this water originates in mountain areas.

- *Biodiversity*
  As noted in Chapter 8, the availability of water is a key factor influencing the distribution of species and habitats, particularly those

Figure 6.4 Annual water balance of Europe, showing the dominant influence of the Alps in producing runoff



Source: Liniger *et al.*, 1998.

Table 6.1 Contribution of the Alps to total discharge of the four major Alpine rivers

	Rhine	Rhone	Po	Danube
Mean contribution of the Alps to total discharge (%)	34	41	53	25
Areal proportion of total Alpine region (%)	15	23	35	10
Disproportional influence of the Alpine region	2.3	1.8	1.5	2.6

Source: Weingartner *et al.*, 2007.

associated with water bodies, flowing water, and wetlands. Habitat loss, fragmentation, changes in agricultural practice, pollution and shifts in water regimes due to climate change, are the most significant reasons for loss of biodiversity.

- ***Energy***
  The use of hydropower varies across countries. The European Environment Agency (EEA) states that: *In the Alps, installed hydropower capacity ranges from more than 400 MW in Germany and Slovenia, to more than 2 900 MW in France, Italy and Austria and over 11 000 MW in Switzerland (CIPRA, 2001). Hydropower is especially important for supplying peak demands (CIPRA, 2001; BFE, 2007a). The water demand of the energy sector is high and generally exceeds the demand of other industrial sectors (Létard et al., 2004)* (EEA, 2009a). Mountains are also major sources of hydropower in other countries, including Belgium, Greece, Norway, Romania and Sweden (European Commission, 2004). This issue is discussed further in Section 6.2. Water originating from mountain areas is also vital for cooling other types of power stations in many parts of Europe, given that 26.5 % of existing power stations in Europe are located in mountain areas (European Commission, 2004). During the 20th century, the number and size of reservoirs rapidly increased (EEA, 2009b).

- ***Forestry***
  As noted in Chapter 7, forests cover around 41 % of the area of Europe's mountains. Tree growth

and the health of forests are crucially dependent not only on temperature, but also on the amount and distribution of precipitation. While forests fulfil a number of different functions, with regard to drinking water, the filtration functions of forests are important for securing water quality (EEA, 2009a).

- ***Households***
  Household use accounts for 60–80 % of the public water supply across Europe (EEA, 2009a, p. 49). Depending on the region, drinking water is obtained to a varying extent from groundwater (Box 6.3), bank filtration, surface water (mostly artificial dams), lakes and springs. In contrast, drinking water in remote mountain areas usually comes from private wells.

- ***Industry***
  Water consumption varies greatly between industries, although there is very little specific information available (Flörke and Alcamo, 2004). For example, in the Rhone basin 6 % of the water abstracted is used for industrial purposes while in river basins in northern Italy the figure is 20 % (DG Environment, 2007; EEA 2009a, p59).

Box 6.3 Transboundary groundwater in the Karavanke/Karawanken

The Karavanke (in Slovenian) or Karawanken (in German) mountain range lies along the border between Austria, Italy and Slovenia. It is a young mountain range which is still developing, lying along the boundary between two continental plates: the large European plate to the north and the smaller Adriatic plate to the south. The thrusting of the Adriatic plate over the European one has resulted in large lateral displacements and the folding of sediments previously deposited in the space between the plates. Much of the Karavanke is built of karstified limestone and dolomite, with underlying paleozoic schists. Precipitation infiltrates into fissures and bedding planes in the karstified rocks, so surface runoff is negligible, and groundwater discharges at large point sources.

The border along the Karavanke is also an orographic divide, with surface water from the south flowing into the Sava and partly also the Drava, and from the north into the Drava. About 3 600 springs occur on both sides of the Austrian-Slovenian border; most have a small discharge. Some very large springs flowing from the karst aquifer — in the area of Peca in the east and Košuta in the centre of the range — have a recharge area extending across the state border. The outflow from some of these springs is up to several hundred litres per second. In addition, many small springs occur in areas whose rocks have a low permeability, e.g. the area of Zgornje Jezersko and Bad Eisenkappel, where mineral waters with a high CO_2 concentration and distinctive geochemistry are found.

With the opening of borders and the membership of both Slovenia and Austria in the European Union, this area, which had previously been sharply divided, became unified and open to development. Numerous plans for tourist developments, especially ski resorts, were prepared. However, such developments must be harmonised with natural conditions, and recognise that the groundwater is of very high quality and high yield; conditions that derive partly from the present settlement situation and relatively poor communication network. At present, larger settlements are supplied with drinking water from both sides of the border.

The existence of transboundary aquifers, large springs used for drinking water supply, and large potential water reserves stimulated the authorities in both countries to support hydrogeological investigations in the Karavanke through the bilateral 'Drava Water Management Commission'. As a result, in 2005, Austria and Slovenia recognised their common transboundary groundwater body, and started to jointly solve questions related to groundwater management. Five distinctive transboundary karstic aquifers with proved transboundary flow were defined.

To date, no detailed investigation has been carried out on the influence of climate change on the water balance of the Karavanke. There are some indications of changes in the precipitation and snowpack regime and their influence on the outflow from the region. However, as the available volume of water is relatively large, and only part of the reserves is used, no problems with water supply are envisaged in the near future.

Source: Mihael Brenčič (Faculty of Natural Sciences and Engineering, University of Ljubljana, Slovenia and Geological Survey of Slovenia), Walter Poltnig (Institute of Water Resources Management, Hydrogeology and Geophysics, Joanneum Research Forschungsgesellschaft m.b.H., Austria).

- ***Navigation***
  The share of freight transport performance on inland waterways in 2006 was 12 % in Germany, and approximately 3 % in France and Austria (Eurostat, 2008). Transportation via the Rhine in Switzerland during 2006 accounted for approximately 9 % of the country's annual external trade (Port of Switzerland, 2007). As mountain rivers are at the upstream end of these waterways, mountain runoff is critical, especially during low flow periods in summer.

- ***Tourism and snow-making***
  Many European mountains are popular holiday destinations. In the Alps, for instance, there are more than 600 ski resorts and 10 000 ski installations, 85 % of which are in France, Switzerland, Austria and Italy (EEA, 2009a). A total of 41.8 million tourist overnight stays were recorded in 2006 in the Austrian Province of Tyrol; 52 % of these were from December to March (Vanham *et al.*, 2008). Reliable snow coverage is a requirement of winter sports and, in recent years, the production of technical snow has become an important issue in most ski areas worldwide and is likely to increase due to climate change (OECD, 2007). Expanding communities and the temporary influx of tourists also put extra pressure on potable water supplies; these impacts are limited both seasonally and spatially.

6.1.2 Pressures and impacts

> *Steep slopes, frequent torrential rainfalls, and pressures such as unsustainable forestry, overgrazing, loss of traditional agriculture, land abandonment and fires are most abundant in mountain areas. In addition to overgrazing due to increased livestock and clear cutting, recent causes of soil erosion and compaction include tourism and sporting and recreational activities (walking, skiing, mountain bikes, off-road vehicles, etc.). Indirectly, soil erosion may cause contamination of surface- and ground-water. Deposits of eroded materials in riverbeds, lakes and water reservoirs might increase flood risks and can damage infrastructures such as roads, railways and power lines* (EEA, 1999a, p. 386).

The long tradition of utilising the energy potential of water has culminated in considerable changes within the natural environment of mountainous regions, such as the Alps. In the future, the combined effects of droughts and increased water consumption in the Alps and other mountain ranges could cause water supply problems throughout Europe; these are likely to be exacerbated by climate change (see Section 6.6).

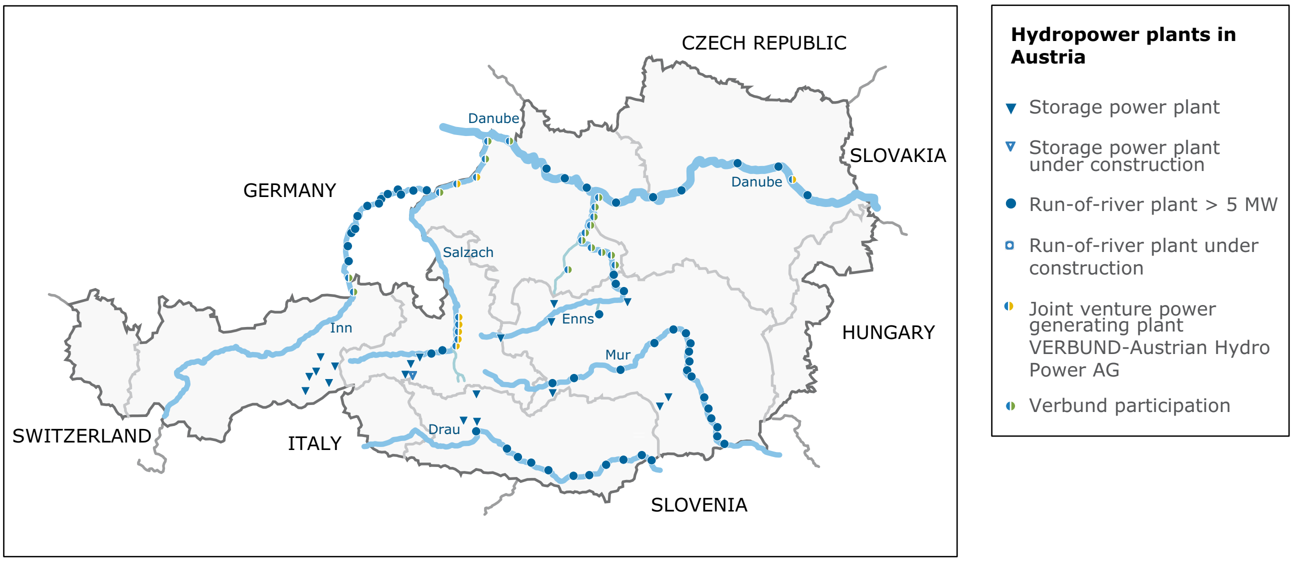
6.2 Hydropower and hydromorphology

6.2.1 Overview of hydropower in European mountain regions

From a purely technical point of view, due to their steep gradients and natural potential for dam sites, mountain valleys are well suited for generating energy through hydropower and storage of water in reservoirs while keeping costs low. However, as discussed below, this is often comes at an observable environmental cost (EEA, 1999a). Approximately 84 % of the electricity generated from renewable energy sources in the EU-15 and 19 % of total electricity production in Europe is generated by hydropower, with small hydropower plants (up to 10 MW) contributing about 2 % of the total electricity generated (ESHA, 2005). Hydropower plants play a key role in the European power grid as their output can also be used to complement other renewable but intermittent energy sources, such as solar and wind, when they are not available (Fette *et al.*, 2007). The majority of suitable sites in the Alps have already been developed, as shown in Map 6.2 for Austria, and export electricity across the European grid and, while hydro-electric generation capabilities have developed in other European mountain regions (Figure 6.5), many potential sites remain (EEA, 1999a).

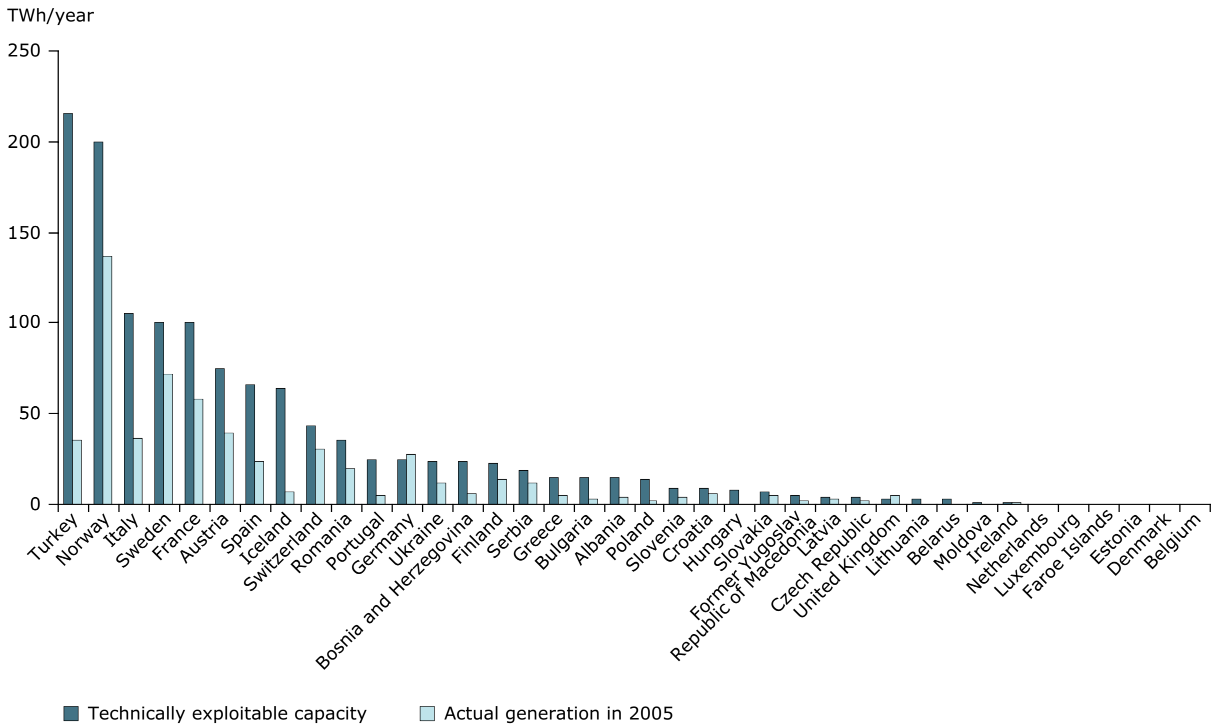
The contribution of hydropower to energy supplies varies considerably among countries, ranging from 0 % to 99 %, with varying shares between different types of hydropower plants (Lehner *et al.*, 2005). Based on the criteria of the International Commission of Large Dams (ICOLD), there are currently around 7,000 large dams (i.e. dams higher than 15 metres or a reservoir with a capacity greater than 3 hm^3) in Europe. The following countries have the largest number of reservoirs: Spain (approximately 1 200), Turkey (approximately 610), Italy (approximately 570), France (approximately 550), the United Kingdom (approximately 500), Norway (approximately 360) and Sweden (approximately 190). A large proportion of these are in mountain areas, though precise figures are not available, and many European countries also have numerous smaller dammed lakes. 'The principle of '20/20/20 by 2020' (a 20 % increase in energy efficiency, a 20 % cut in greenhouse gases and a 20 % share of renewables in total EU energy consumption, all by the year 2020), is likely to put further pressure on water resources

Map 6.2 Hydropower plants in Austria



Source: Based on Verbund AG.

Figure 6.5 Hydropower in Europe: technically exploitable capacity and actual generation in 2005



Source: World Energy Council, Survey of Energy Resources 2007.

in the attempt to increase the share of renewable energy in the form of hydropower' (Alpine Convention, 2009, p. 154).

6.2.2 *Impact of reservoirs and hydropower on hydromorphology*

Despite the economic costs of production being relatively low, the environmental costs of reservoir construction are often very high and include sediment discharge, bank erosion, and changes in riparian biological diversity, difficulties of fauna migration, changes in microclimate, reservoir eutrophication, loss of farmland, changes in natural habitats and landscape, a rise in groundwater levels and contamination (EEA, 1999a; EEA, 2010). Rivers are transformed into a hybrid, neither a river nor a lake, changing environmental conditions such as currents, nutrients and light (Kristensen and Hansen, 1994; EEA, 1999a; EEA, 1999b). While it is has long been recognised that dams obstruct migration patterns of fish and other organisms, new research suggests that they also affect water temperature and the build up of silt downstream, and that short-term peaks of water flow negatively impact on fish and their habitats (Fette *et al.*, 2007).

The disconnection of wetlands or natural floodplains and water abstraction alter the hydrological and biological make-up and structure of a river; retained sediment upstream may mean problems for the supply of drinking water and increased erosion, causing damage to infrastructure, while increased sediment downstream may mean that material has to be brought in to help stabilise an eroded river bed (Kondolf, 1998; ICPDR, 2010). Most European rivers are already heavily affected by dams and reservoirs and most of the suitable stretches have already been used. However, there are still many plans and studies for new dams, reservoirs and small hydropower projects, which may conflict with the objectives of the Water Framework Directive (WFD) of achieving good ecological status (see Chapter 11). The Danube, for example, is highly regulated along over 80 % of its length; cut off from its floodplains, the frequency and duration of flooding events has changed, and its former floodplains are ecologically degraded (ICPDR, 2010). However, there are plans to build dams on the Bavarian Danube, the Sava, and the Drava along the Croatian-Hungarian border. On the Drava, the Novo Virje dam (planned capacity: 121 MW) would break up the still largely pristine 370 km stretch of river along the Mura and Drava between the Austrian border and the Danube (ICPDR 2010).

Increasing recognition of the environmental and social issues related to the construction and operation of hydropower facilities underlines the need for constructive debate on possible water allocation under scenarios of reduced or altered future river flows. Given the significant role of hydropower, Europe's present capacity and future potential for hydroelectricity generation and its mid- and long-term prospects require an assessment of the possible impacts of climate and water use changes on regional discharge regimes and hydroelectricity production. This will be critically important for the sustainable management of Europe's water resources (Lehner *et al.*, 2005). Furthermore, the measures taken to ensure 'good practice' within hydropower schemes are also site-dependent, i.e. the same measure can be in different circumstances either 'restoration' or 'mitigation' (SedNet, 2006, p. 9).

6.3 Water quality

While some water bodies are still subject to excessive nutrient inputs or contamination, water quality in European lakes and rivers has been substantially improved in recent decades due to major wastewater treatment efforts. About 20 years ago, phosphorus inputs to water bodies were mainly due to the lack of adequate wastewater treatment facilities. The expansion of treatment works, moving the pollution downstream from lakes, and the ban on phosphates in detergents (e.g. introduced in 1986 in Switzerland) has led to a substantial reduction of phosphorus concentrations in watercourses and lakes (Figure 6.6). However, levels of organic micro pollutants such as endocrine disruptors, biocides and pharmaceuticals are increasing (Schärer, 2009).

Large deep lakes, which are mainly in mountain areas and are crucial for the supply of water in several European regions, are mostly glacial in origin and retain their own unique characteristics in comparison to other water bodies (see also Box 6.4). The catchment as a whole needs to be included in the management of these lakes to attain or maintain good ecological status (Eurolakes, 2004). For example, due to accumulative anthropogenic pressures, the water quality and ecology of Lac du Bourget in France have become increasingly threatened, particularly from eutrophication; recognition of these problems has led to a 15-year catchment plan to help manage the lake more sustainably (Eurolakes, 2004). Few, if any, European mountain lake ecosystems are pristine, with nearly all contaminated in some way by atmospherically-transported pollutants, and in

Box 6.4 Large old lakes in southeast Europe

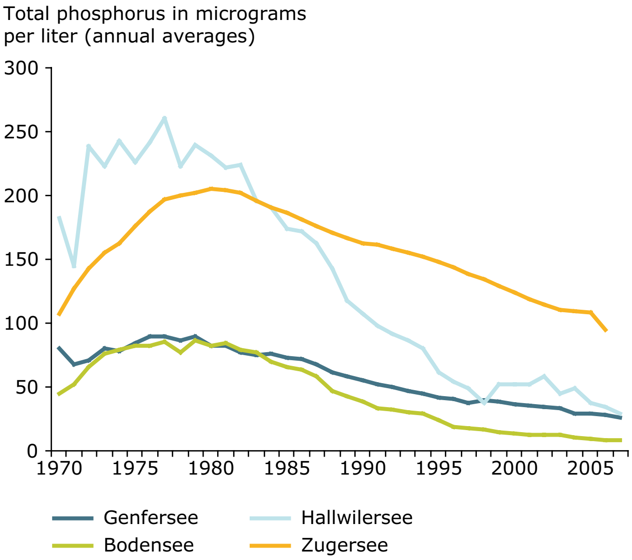
Most of Europe's lakes were formed during or after the last glaciations; however, there are a few very old lakes, including: Lake Ohrid, on the mountainous border between south-western Former Yugoslav Republic of Macedonia and eastern Albania; and the two lakes within the Prespa basin, shared by Greece, Albania and the former Yugoslav Republic of Macedonia. Located within mountain ridges, they were formed probably 3–5 million years ago by earthquakes that fractured the landscape, often creating very deep lake bowls. Because these lakes are so old, and the mountains isolated them from other waters, a unique collection of plants and animals have evolved in them. While some of these species of plants and animals were common millions of years ago, these 'relicts' or living fossils have virtually disappeared from other European lakes.

During the last 50–100 years, the populations within the catchments of the old lakes have markedly increased. The population in the Lake Ohrid catchment, for example, is five or six times larger now than at the end of World War II (EEA, 2003). In the past 15 years, a significant decline of the level of Lake Prespa has been observed, causing environmental and water resources management concerns. Population growth and development have impacted the old lakes in many ways and they are threatened by human activities such as: tourism development; water diversion resulting in lowering of water levels; damming for hydropower; and pollution from agriculture, waste water and mining — particularly near the sites of the old chromium, iron, nickel and coal mines outside Pogradec (EEA, 2003). Wastewater often receives limited treatment and is discharged, resulting in eutrophication and microbiological pollution. The lakes are also affected by agricultural activities such as the use of fertilisers and pesticides in the catchments which also results in pollution.

The common problems of Lake Ohrid encouraged the governments of Albania and the former Yugoslav Republic of Macedonia to come together and sign an agreement on 20 November 1996 to begin the Lake Ohrid Conservation Project. It has four components: institutional strengthening; monitoring; participatory watershed management; and public awareness and participation. Its objective is to conserve and protect the natural resources and biodiversity of Lake Ohrid by developing and supporting effective cooperation between Albania and the former Yugoslav Republic of Macedonia for the joint environmental management of the watershed.

Source: Sue Baggett (Independent Consultant, the United Kingdom).

Figure 6.6 Phosphorous levels in the water of large mountain lakes in Switzerland



Source: Federal Office for Statistics, Switzerland.

some cases a level of contamination sufficiently high to have caused significant ecological change 'due to remaining threats from increased nitrogen deposition, trace metals and continual organic pollutant bioaccumulation' (Battarbee *et al.*, 2009).

A number of land-use activities also directly or indirectly affect the quality of mountain water; the history of changes in land use and streams in Switzerland is representative of many mountainous regions in Europe (Wohl, 2006). While atmospheric deposition has been and continues to be a major pressure on upland water quality, increasing concern has been voiced recently regarding the effect of changes in upland use; for example, the impacts of agriculturally-derived diffuse pollution (Stevens *et al.*, 2008), overgrazing and plantation forestry practices (Emmett and Ferrier, 2004). Highland streams are generally clearer than lowland streams. For example, in the United Kingdom, concentrations of nitrate and orthophosphate in upland rivers are 3 to 10 times lower than lowland arable and pasture

Box 6.5 Carpathian streams as a reference for defining ecological integrity and the EU Water Framework Directive

The conservation and restoration of aquatic ecosystems require biodiversity assessment methods and ecological performance targets derived from agreed policies. First, there is a need to evaluate the usefulness of indicators in assessing gradients from reference conditions for ecosystem functionality to anthropogenically-disturbed sites (e.g. Degerman *et al.*, 2004). Second, the functionality of indicators should be evaluated with respect to how the results from monitoring could be communicated to, and used, by different societal actors (Törnblom and Angelstam, 2008). The landscapes of the Carpathians, spanning a steep gradient of land-use intensity, offer unique opportunities to evaluate such methods. This ecoregion has a great variation in the environmental history of forest and agricultural ecosystems among its countries, thus providing a suite of unique landscape-scale experiments. Landscape composition, riparian vegetation and instream habitat characteristics with stream macroinvertebrate assemblage structure were compared in 25 catchments located in Poland, Ukraine and Romania (Törnblom, 2008). This macroinvertebrate based methods have been in use for assessing biological quality of streams for at least four decades and are well documented.

First, the use of three types of data — data at higher taxonomic levels, species-level data, and abundance data — for assessing macroinvertebrate species richness in second and third order streams was evaluated. The number of families was a reliable indicator of species richness within Ephemeroptera, Plecoptera and Trichoptera (EPT), suggesting that analyses focusing on this taxonomic level could offer a cost-efficient alternative to species-level assessments. Species richness of Trichoptera was strongly correlated to species richness in Ephemeroptera and Plecoptera, and thus representative of the EPT group as a whole, whereas species richness in Ephemeroptera and Plecoptera did not perform as well. Taxa richness in EPT was generally positively related to forest cover in the catchments and negatively related to the proportion of agricultural land. Loss and fragmentation of forests were major threats to ecological integrity.

Second, the abundance and numbers of taxa of Plecoptera were compared with forest proportions in the catchments and logistic regression was used to identify thresholds associated to forest proportion as a surrogate for catchment integrity. Plecoptera abundance and Plecoptera taxa richness were positively correlated both to each other and to forest proportion, but negatively correlated to catchment area, inorganic carbon, alkalinity and conductivity. Abundance gave a higher rate of correct classification of catchments with a high forest proportion than did taxa richness. Considering this, and because non-experts find counting Plecoptera individuals easier than recognising different Plecoptera taxa, abundance was chosen as an indicator. This dose-response study of habitat characteristics and Plecoptera abundance indicates that this group is an effective bioindicator in headwater catchments for predicting the ecological status of headwater streams. A decrease of the forest proportion of catchments below 79 % will reduce or affect Plecoptera abundance and taxa richness in second-order streams.

Further studies are required to validate these results in other regions and to develop methods to effectively communicate the requirements of indicator taxa to managers and other stakeholders in rivers and streams. Assuring that ecological indicators have a high communication value, and collaborative spatial planning using an integrated landscape approach for restoring ecological integrity in impaired streams to whole catchments are key challenges to be solved. However, there is a mismatch between the need for such systematic planning and reality: monitoring programs and performance targets for assessment need to be in place, and supported by tools for adaptive governance and management towards ecological integrity by both formal and informal organisations. In addition to hierarchical planning, participatory approaches that include relevant actors and stakeholders and that enhance communication and collaboration are needed. Applied interdisciplinary research is also required in order to operationalise 'good ecological status' and 'ecological integrity', and to understand how local and regional governance arrangements can deliver good ecological status as prescribed by the Water Framework Directive (WFD).

Source: Johan Törnblom and Per Angelstam (School for Forest Engineers, Swedish University of Agricultural Sciences, Sweden).

rivers (DEFRA, 2010). Upland waters also play a vital role in the dilution of pollutant discharges downstream (Stevens *et al.*, 2008). Reliable methods for monitoring the quality of mountain waters are essential (Box 6.5).

6.3.1 Long-range transportation and acidification

Since the recent widespread decline of sulphate concentrations in lakes and streams (see Box 6.6), nitrate concentrations have assumed greater importance as an acidifying anion. Within the monitoring sites of the International Cooperative Programme on Assessment and Monitoring of Acidification of Rivers and Lakes (ICP), no major trends in nitrate concentrations are evident at present (NIVA, 2008). While there is no evidence of widespread decline of NO_3 in alpine areas, recovery may be delayed by a re-acidification effect, as it is leached from soils to surface water; this may be further exacerbated by climate change (Rogora *et al.*, 2008). A study of long-term trends of N-NO_3 concentrations in 10 rivers draining the forested catchments of Piedmont of northwest Italy and the Swiss Canton of Ticino show that warm periods were normally followed by an increase of N-NO_3 in the river water as mineralisation and nitrification of the soil were enhanced (Rogora, 2007).

The biological recovery of surface water bodies is attained when their chemical composition can sustain acid-sensitive species. The relationship between their acid neutralising capacity (ANC) and biological response is a robust indicator of the effect of water quality on populations of key freshwater species, such as the brown trout (NIVA, 2008). Signs of recovery of invertebrates in the Scandinavian countries, the United Kingdom and the Czech Republic are evident and well-documented, but improvements in water quality in the most acidified sites in central Europe have yet to reach a level which allows widespread biological effects to be detected (NIVA, 2008). Dynamic modelling of surface water chemistry indicates that, under current legislation, adverse biological effects associated with acidification will continue to be a significant problem in the Tatra mountains in Slovakia, Italian Alps, southern Pennines in the United Kingdom, southern Norway, and southern Sweden (NIVA, 2008).

In the Alps, the consequences of acid precipitation may be exacerbated by the fact that precipitation increases with altitude, and thus the deposition of hydrogen ions increases strongly with height. Since the concentration of basic anions and cations in precipitation is rather uniform over central Europe, the Alps receive as much acid deposition as other areas because of the orographic controls on precipitation, although they are not a major source of sulphate-based pollutants (Beniston, 2006).

A key question is whether current protocols and directives, when fully implemented, will lead to a more complete recovery to the 'good ecological status' required by the WFD (Battarbee, 2004; Battarbee *et al.*, 2009).

> *The successful management of rivers for water quality requires scientific knowledge presented as well-grounded ecological principles in a format that is easily accessible and usable by water managers, linked to a political agenda and funding for their implementation. The nursing and sustaining of political commitment usually necessitate increased communication and education across disciplines and spatial scales, and between scientists, managers, and stakeholders to facilitate an integrated view of freshwater resources...* (Nilsson and Malm Renöfält, 2008, p. 10).

6.3.2 Impacts of mining

Acid drainage is the single greatest environmental challenge in the mining sector and the industry's primary source of long-term pollution. It often becomes more acute after a mine is closed due to 'groundwater rebound'. The problem of acid drainage is visible at both active and abandoned mine sites. Capturing mine waters within mountainous areas is further complicated by the fact that chances of dispersal are greater due to gravity, geological structure and morphology. Water management in mining is both costly and a major environmental concern. While some mines are still active in Europe (e.g. Sweden has substantial base metal, gold and iron ore deposits that are still actively mined and developed), most ore fields are now abandoned, and the emphasis has shifted to the control of their environmental impact and remediation, including their effect on water quality (Wolkersdorfer and Bowell, 2005). The WFD applies to mining only in the generic sense. The mining industry's lack of concern regarding their environmental impact in the past is well documented; while many modern mines are obliged to pay more attention to their effluent and liquid discharge, accidents do happen (Fox, 1997).

After the mining accidents in Aznalcollar, Spain (April 1998) and Baia Mare, Romania (January 2000), the European Commission formed the Baia Mare Task Force (March 2000) to put together an action plan (Amezaga and Kroll, 2005). In their

Box 6.6 Impact of the acid atmospheric deposition and commercial forest practices in protected watersheds of the Jizera Mountains (Czech Republic)

The Jizera mountains are part of the 'Black Triangle' — the epicentre of acidity in Europe. The native tree species are mainly Common beech (*Fagus sylvatica*), Norway spruce (*Picea abies*) and Common silver fir (*Abies alba*). In the 18th and 19th centuries, native stands were converted to spruce plantations, which now comprise almost 90 % of the local forests.

The control of forests in the Jizera Mountains began in the early Middle Ages, with the protection of the state border and an emphasis on maintaining populations of game animals. In 1902–2009, after several catastrophic floods, reservoirs were constructed to protect lowland cities against flooding. In the second half of the 20th century, the system of drinking water supply was developed. To support water and soil conservation, the 'Protected Headwater Area of the Jizera Mountains' was proclaimed by the Czech Government in 1978. Environmental watershed practices included limits to clear-cutting, peatland drainage, and heavy mechanisation.

The slow weathering bedrock and pure podzolic soils have a small buffering capacity. In the 1970s and 1980s, the forests of the headwater catchments declined as a consequence of the acid atmospheric load (sulphate) and commercial forestry practices: spruce plantations of low stability were extensively clear-cut, using wheeled tractors, and both the control of insect epidemics and reforestation were ineffective. Both runoff and the water quality in watercourses and reservoirs deteriorated. Without pollution or acid rain, most lakes and streams would have had a pH near 6.5. In surface waters, extremely low pH (pH 4–5) and, consequently, high levels of toxic metals (aluminium, 1–2 mg/l) led to the extinction of fish and drastically reduced zooplankton, phytoplankton, and benthic fauna. The response to defoliation and the die-back of spruce plantations was an extended harvest. The network of skid-roads — and the related length of drainage — increased from 1.3 km/km^2 to 4.7 km/km^2, and the infiltration capacity of affected soils decreased from 150 m/hour to 40 mm/hour. With the drop in evapotranspiration, the annual water yield increased by 108 mm, but the direct (fast) runoff intensified from 50 % to 70 % of the annual runoff. The erosion of soil increased from 0.01 mm/year to 1.34 mm/year, and almost 30 % of the eroded volume of sediment was lost in runoff.

In the 1990s, the first signs of recovery in surface waters appeared, resulting from: decreased air pollution (approximately 40 % of SO_2 levels measured in the mid-1980s); a significantly reduced leaf area of forest canopies after the harvesting of spruce plantations (leaf area index dropped from 18.0 to 3.5); and, partly, by liming some reservoirs and watersheds. Traditional forestry practices — skidding timber by horses or cables, respecting riparian zones, seasonal skidding, and manual reforestation — have also contributed to the stabilisation of mountain catchments. Mean annual pH values increased to 5–6, and aluminium concentrations dropped to 0.2–0.5 mg/l. As some physical and chemical parameters in surface waters improved, fish were reintroduced: brook char (*Salvelinus fontinalis*, an acid-tolerant species) and brown trout (*Salmo trutta* morpha *fario*), which is native to the region. In the late 1990s, the population of char survived and reproduced, while brown trout starved in the headwaters. There is a relatively long delay between the drop in the atmospheric load and progress in the biota. Environmental indicators show a delay of almost 10 years, and the composition of algal mats and fish populations in surface waters take even longer to respond to the environmental changes.

Acid atmospheric deposition in forests rises with canopy density (total leaf area) and height (related to roughness, and wind turbulence). Consequently, the clear-cutting of spruce plantations led to some positive impacts on the recharge of water supplies. In addition, beech stands which, in comparison to spruce plantations, have less canopy (particularly in the dormant season when the SO_2 concentration in the atmosphere is higher) and a higher buffer capacity provide higher yields of water, which is of better quality; and base flow is higher, while direct flood flow is lower. In a long-term perspective, water quality might be improved by planting stands whose species composition is nearer to that of native forests — and which might be less endangered by climate change than spruce forests. The negative impact of forest practices on soil erosion, sedimentation and contamination of surface waters, observed in the 1980s, can also be avoided by alternative techniques: skidding timber using horses or cables, and respecting riparian buffer zones.

Source: Josef Krecek (Department of Hydrology, Czech Technical University in Prague, Czech Republic).

environmental assessment of the Tisza river basin (TRB), UNEP (2004) warned of the environmental risks from flooding and industrial pollution of rivers within the basin, particularly heavy metal pollution originating from the mining and metal processing industries located upstream in northern Romania. The TRB assessment specifically noted: pollution by heavy metals with a high rate of toxicity at small concentrations (e.g. lead and cadmium) affecting natural fishery resources in the Romanian area of the TRB; destruction of planktonic and benthonic biocenoses in a 24 km stretch of the Abrudel River due to persistent pollution with highly acidic mine wastewater containing heavy metals; and the destruction of resident aquatic species by wastewater along a 10 km section of the Ampoi River downstream from the Zlatna industrial plant. A long-term recommendation by UNEP (2004) was that an integrated sustainable development strategy for the management of land and water should be agreed upon by the countries sharing the TRB, with the support of both their national governments and international communities. The acquisition of in-depth knowledge and information regarding natural processes and human ecology within a mountain region, along with the biological relationships with montane habitats, is key to preventing mining catastrophes if further environmental damage is to be avoided (Fox, 1997).

6.4 Floods

Despite considerable variation between different mountain areas, they all have complex topography. Their orographic features include some of the sharpest gradients coupled with rapid changes in climate, vegetation and hydrology due to altered elevation over comparatively short horizontal distances (Whiteman, 2000). Due to their topography, mountain regions are more flood-prone (EEA, 1999a). Flood types include large-scale river floods, flash floods, ice-jam, and floods due to snow melt; inland river floods are predominantly linked to prolonged bouts of rain, heavy precipitation events or snowmelt. River floods are the most common natural disaster in Europe, sometimes resulting in widespread damage to infrastructure, huge economic and production losses, loss of life especially in the case of flash floods, displacement of people, and can be damage to human health and the environment (EEA, 2008).

6.4.1 Overview of recent flood damage and costs

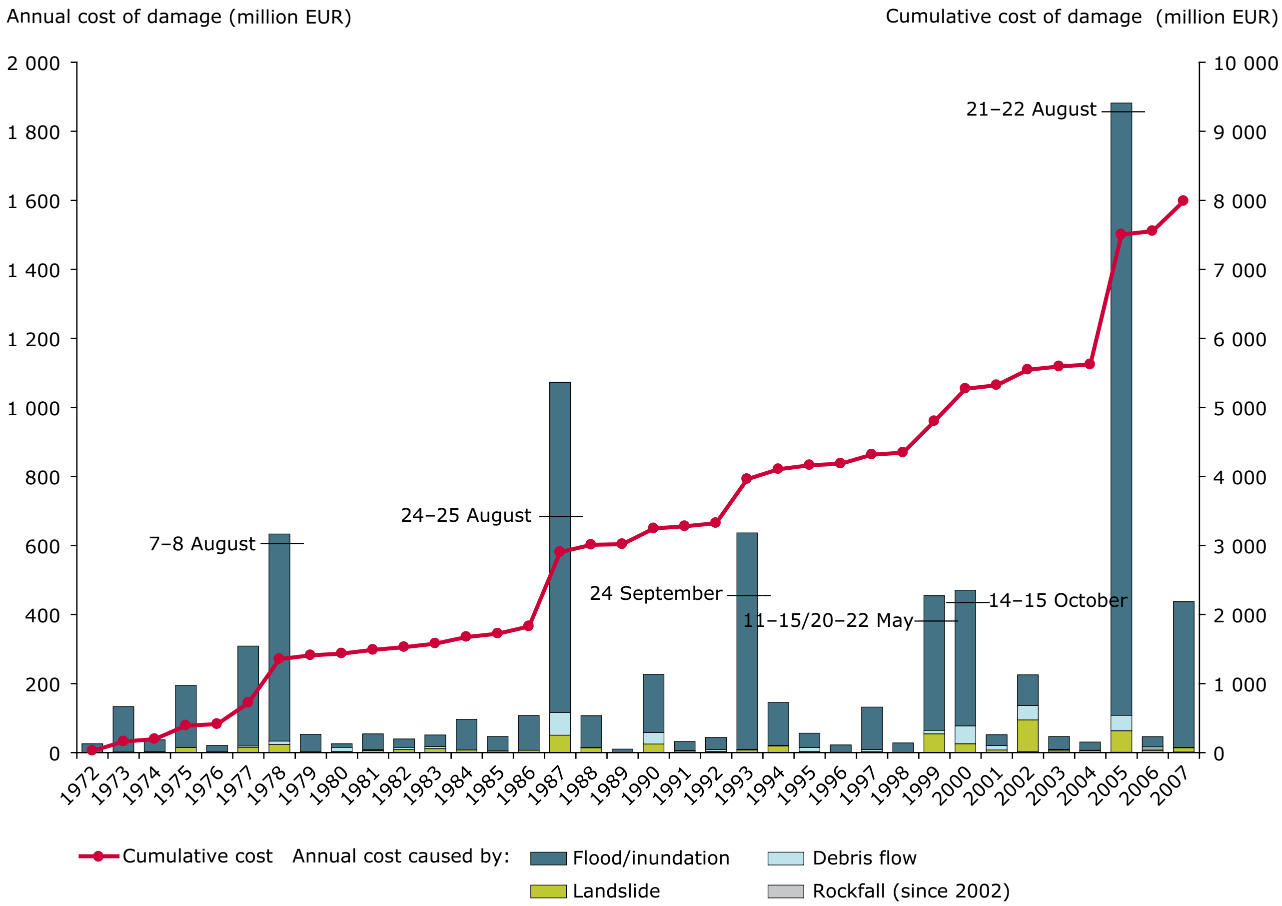
The occurrence of river flow maxima doubled in Europe between 1981 and 2000 when compared to 1961 and 1980; since 1990, 259 major river floods have been reported in Europe, 165 since 2000 (EEA, 2008). However, whether this can be regarded as a trend is not certain, as periods with few floods alternate with periods with frequent floods over long periods (Schmocker-Fackel and Naef, 2010). The rise in the number of reported flood events over recent decades is also due both to better reporting and to land-use changes (EEA, 2008). For example, Swiss flood damage data collected between 1972 and 2007 reveal that most of the damage was caused by a few severe events: six single flood events in 1978, 1987, 1993, 1999, 2000 and 2005 each caused damage costing more than EUR 350 million, contributing to 56 % of the total sum (Hilker *et al.*, 2009). The proportion of the total estimated damage (EUR 8 billion) caused by the different processes in the investigated period are shown in Figure 6.7. While 89 % of the costs (EUR 7.11 billion) were due to floods and inundations, debris flows elicited only about 4 % (EUR 340 million), landslides 6 % (EUR 520 million) and rockfalls less than 1 % (EUR 15 million) of the total costs (Hilker *et al.*, 2009). Heavy rains in the Carpathian Mountains at the end of July 2008 caused rivers in Ukraine, Moldova and Romania to flood towns and villages, submerging homes and displacing tens of thousands of people. The direct damages exceeded EUR 1 billion (WHO, 2008a, b).

6.4.2 Flood protection

Riparian wetlands are useful for their ability to not only reduce nutrient loading in rivers but also to provide flood protection (Nilsson and Malm Renöfält, 2008). In the case of the Danube, for example, where over 80 % of former floodplains have been lost during the last 150 years, significant flood protection and other ecosystem services could be regained by their enhancement and restoration (WWF, 2008). In the Rhine basin, the best protection against flooding is to make space for the river to flood certain areas, in order to protect others from being flooded (Scholz, 2007). Setting aside certain areas for flooding could thus both protect valuable land and reduce the risk of pollutants being washed out in the water (Nilsson and Malm Renöfält, 2008).

The need for flood protection within the major floodplains of northern Europe has generally received a higher level of attention than protection against water scarcity and droughts. Transboundary cooperation and handling of cross-boundary issues between different states has taken place in a number of flood protection schemes, e.g. (i) The Flood Early Warning System for the River Rhine (FEWS-Rhine), developed by a Swiss-Dutch-German consortium in close coordination with Germany

Figure 6.7 Annual and cumulative cost of damage caused by floods/inundation, debris flows, landslides and rockfalls for 1972 to 2007, as well as the total costs of the six major flood events indicated by short horizontal lines and date



Note: The p-value for the total cost of damage is 0.29, which indicates there is no statistically significant trend in the data.

Source: Hilker *et al.*, 2009, p. 916. This work is distributed under the Creative Commons Attribution 3.0 License.

and the Netherlands, enabling flood forecasts and warnings for the Rhine, its tributaries and for the major Swiss lakes within the basin; (ii) on the highly modified river Rhône which has many diversions, reservoirs and power plants, a forecasting and flood management system (MINERVE) is being developed (EEA, 2007). In such schemes, accurate prediction and monitoring of water coming from upstream mountain catchments, as well as better coordination and information exchange, are essential.

6.5 Climate change and impact on water temperature and ice cover

6.5.1 *Increasing water temperature in rivers*

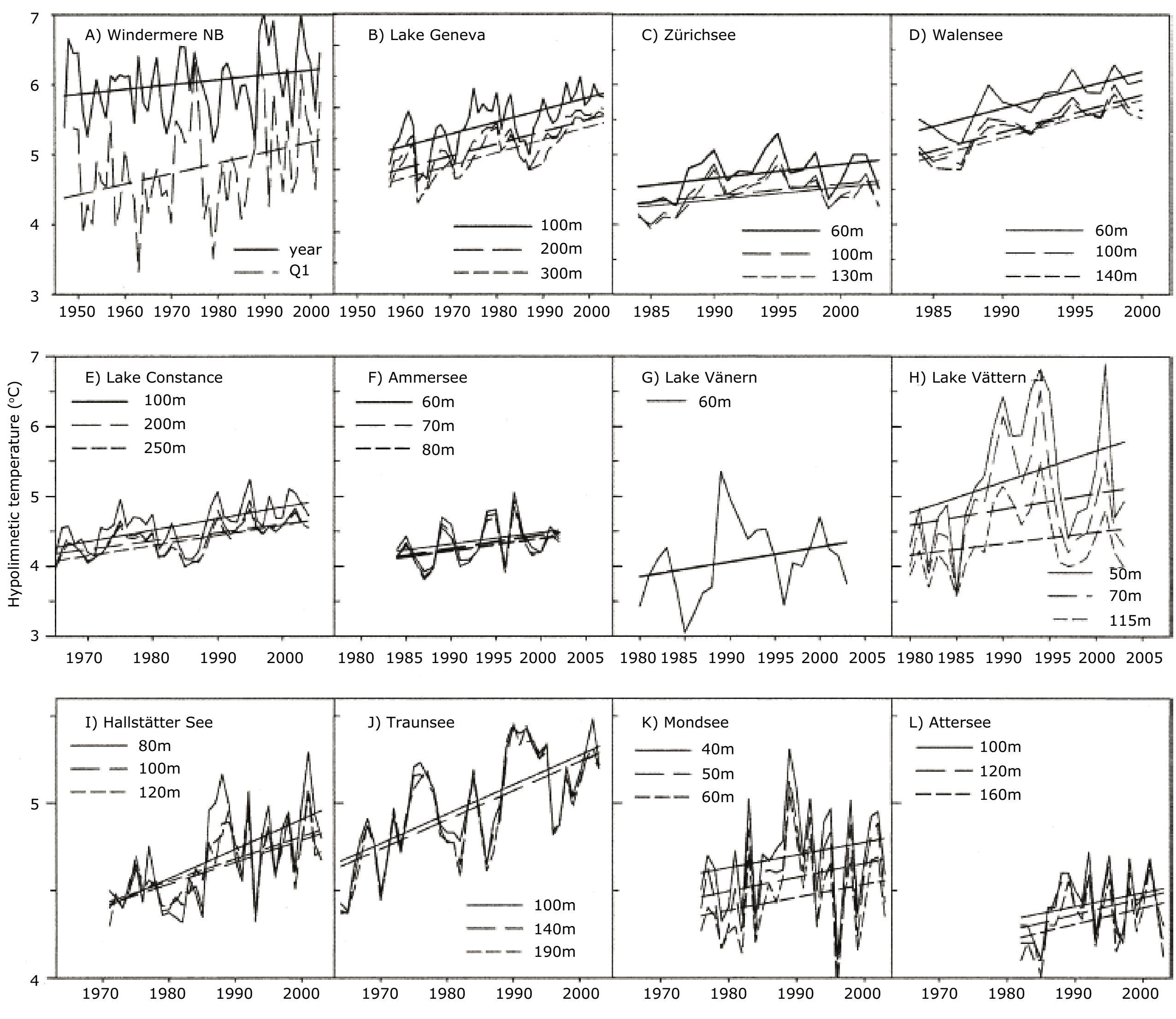
Generally, there is a strong correlation between air and water temperature (EEA, 2008). In addition to climate warming, flow regulation and cooling water from thermal power plants increase river temperature in larger rivers, while deforestation can have a strong impact on the heat balance of smaller streams. The surface temperatures of some major rivers have increased by 1–3 °C over the past century; shorter time series of 30 to 50 years show increases of 0.05–0.8 °C per decade. It is projected that climate change will result in increases in river temperature of 50 % to 70 % of projected air temperatures (EEA, 2008).

6.5.2 *Implications of increasing lake temperature*

For Northern European lakes, the most important climatic effects which have been experienced are the increased length of ice-free periods (Weyhenmeyer *et al.*, 1999; 2005). For Western European lakes, increased winter rainfall (George *et al.*, 2004) and changes to the frequency of calm summer days are more significant (George *et al.*, 2007; George, 2010).

Annual mean deepwater (hypolimnetic) temperature data spanning 20 to 50 years, taken from 12 deep lakes across Europe, show a 'high degree of coherence among lakes, particularly within geographic regions', with temperatures varying between years but increasing consistently in all lakes by about 0.1–0.2 °C per decade (Dokulil *et al.*, 2006) (Figure 6.8). However, there are two exceptions, both of which are remote, less wind-exposed alpine valley lakes: '[i]n four of the deepest lakes, the climate signal fades with depth. The projected hypolimnetic temperature increase of approximately 1 °C in 100 years seems small. Effects on mixing conditions, thermal stability, or the replenishment of oxygen to deep waters result in accumulation of nutrients, which in turn will affect the trophic status and the food web' (Dokulil *et al.*, 2006, p. 2787). Since 1950, water temperatures in some rivers and lake surface waters in Switzerland have increased by more than 2 °C (BUWAL, 2004; Hari *et al.*, 2006). In the large lakes in the Alps, the water temperature has generally increased by 0.1–0.3 °C per decade (EEA, 2008): Lake Maggiore and other large Italian lakes (Ambrosetti and Barbanti, 1999), Lake Zürich

Figure 6.8 Time series and regression lines for annual average deepwater temperatures



Note: (A) Windermere North Basin 60 m and the first 10-week period (Q1), (B) Lake Geneva, (C) Zürichsee, (D) Walensee, (E) Lake Constance, (F) Ammersee, (G) Lake Vänern, (H) Lake Vättern, (I) Hallstättersee, (J) Traunsee, (K) Mondsee, and (L) Attersee for the depths indicated . T-increase in all lakes was 0.1–0.2 °C/decade.

Source: Dokulil *et al.*, 2006.

(Livingstone, 2003), Lake Constance and Lake Geneva (Anneville *et al.*, 2005). Similarly, studies of ice cover information on 11 Swiss lakes over the last century, show that ice cover has significantly reduced in the past 40 years, especially during the past two decades; this trend is more evident in lakes that rarely freeze as opposed to lakes that freeze more frequently (Franssen and Scherrer, 2008). With climate change, more stable vertical stratification and higher surface and deep water temperatures are predicted (EEA, 2008).

6.5.3 *Ecological impacts of higher water temperature*

Ecological impacts of higher water temperatures have been studied in rivers and lakes (EEA, 2008). Increased thermal stability in lakes has led to increased anoxic conditions. Larger refugee zones for visually-oriented fish predators due to higher thermal stability influence the population density of invertebrate predators in a lake, an illustration of how climate change can affect the pelagic food web. Earlier algal blooms are predicted. In rivers, increased water temperatures: reduce the available habitat for cold-water species such as brown trout, which may be replaced by more thermophilic species; increase the incidence of temperature-dependent illnesses; threaten scarce invertebrate water species; and lead to oxygen depletion.

Future water quality degradation may not only be due to expected climate change but is also likely to be due to new agricultural and industrial development. Due to limited data and the highly varied nature of climate over uplands, few studies have quantified the potential impact of climate change on water quality (Stevens *et al.*, 2008). However, expected changes that could result in failure to reach water quality standards include: increased water temperature and reduced dissolved oxygen; decreased dilution capacity of receiving waters; increased erosion and diffuse pollution; photoactivation of toxic substances; metabolic rate change of organisms; augmented eutrophication; and greater prevalence of algal blooms (Wilby, 2004; Wilby *et al.*, 2006). Insufficient water during periods of low flow could also severely limit water abstraction in the uplands (Stevens *et al.*, 2008). The frequency of catastrophic hydrological extremes could increase, alternating between drought and rapid runoff with downstream flooding. The extremity of water flows could further lead to soil erosion, landslips and sedimentation, while changes in soil quality could in turn reduce water quality and lead to the gradual and pervasive degradation of rivers (EEA, 2009a).

6.6 Climate change impacts on water availability

As water is intricately linked to climate through a number of connections and feedback cycles, any alterations within the climate system will initiate changes in the hydrological cycle (EEA, 2008). Increased glacier retreat (Box 6.2) and permafrost degradation, as well as changes in precipitation and decreases in the depth and length of snow cover (Stewart, 2009; EEA 2009a) have been observed in many mountain areas in Europe. In the southern Alps, groundwater levels in some regions have dropped by 25 % over the past 100 years (Harum *et al.*, 2001). Projected changes in precipitation have been described in Section 5.2.2.

> *Slight changes in the mean annual temperature may coincide with dramatic changes on an hourly, daily or even monthly basis, which is the time frame relevant for natural hazards, permafrost degradation and many other developments. Changes in the temperature and precipitation patterns have various consequences on a mountain environment, for example, snow cover reduction, glacier retreat, thawing of permafrost, vegetation shifts. Global warming might change the river discharge patterns including an increase in the frequency and intensity of floods and droughts...* (ClimchAlp, 2008).

Regional climate scenarios suggest that, by 2050, there will be an increase in mean winter precipitation of 8 % compared to 1990 to the north of the Alps, and 11 % to the south of the Alps, with respective decreases of 17 % and 19 % in summer. The impact on the hydrological cycle in the Central Plateau and in the very south of Switzerland will be marked:

> *...small and medium water-courses will dry up more frequently and natural replenishment of groundwater will decrease accordingly. Apart from changes to the average precipitation rate, increased intensity of storms and reduced snowfall and snow cover duration are expected in the coming decades...The warming trend and changing precipitation patterns are expected to have significant effects on ecosystems... Switzerland intends to include adaptation in its future climate legislation, in parallel with efforts aimed at greenhouse gas emissions reductions...* (FOEN, 2009).

6.6.1 *Changes in glacier and snow storage*

Glaciers are important for water storage and accumulation, however, due to increasing temperatures and extended dry periods, it appears that their ability to fulfil this function is diminishing. Glacier mass balance has responded very sensitively and negatively to warming since the end of the European 'Little Ice Age' in the mid-19th century (Haeberli and Beniston, 1998; Box 6.2). The shrinking of glaciers, permafrost and snow cover (Section 5.2.3), changes in precipitation patterns and increasing temperatures will severely change alpine habitats and thus influence the ecosystem services they provide (Beniston, 2006; EEA, 2009a). 'In snow-dominated regions, such as the Alps, Scandinavia and the Baltic, the fall in winter retention as snow, earlier snowmelt and reduced summer precipitation will reduce river flows in summer (Andréasson *et al.*, 2004; Jasper *et al.*, 2004; Barnett *et al.*, 2005), when demand is typically highest' (EEA, 2008, p. 95).

While climate change is one reason it is not the only one, for example, for the use of snow-making facilities in ski resorts, as technically produced snow is the most used adaptation strategy for extraordinarily warm winter seasons (Vanham *et al.*, 2008). Snowmaking is a short- to medium-term adaptation strategy not only for high-altitude ski resorts, but also for financially strong year-round destinations at lower elevations, such as Kitzbühel, Austria (altitude 762–1 995 m) (Steiger and Meyer, 2008). The natural altitudinally-dependent snow line is losing its relevance for Austrian ski lift operators, where 59 % of the ski area is covered by artificial snowmaking due to trends in tourism, prestige, and competitive advantage; 'despite the fact that snowmaking is limited by climatological factors, ski lift operators trust in technical improvements and believe the future will not be as menacing as assumed by recent climate change impact studies' (Vanham *et al.*, 2008, p. 292).

6.6.2 Changes in seasonality of river runoff

There is some indication that annual river flow and the seasonality of river flow in Europe during the twentieth century was influenced by climate change (Figure 6.9). Climate change is projected to lead to strong changes in yearly and seasonal water availability across Europe (Beniston, 2006). A rising trend in annual flows within northern parts of Europe (with increases mainly in winter) and a decreasing trend in southern parts of Europe are evident (EEA, 2009b). Seasonal changes in river flows are also projected. For example, higher temperatures will push the snow limit in northern Europe and in mountainous regions upwards, and reduce the proportion of precipitation falling as snow. This would result in a marked drop in winter retention and higher winter run-off in northern European and Alpine rivers such as the Rhine, Rhône and Danube. The behaviour of winter snow pack is a key variable which controls the numerous components of the hydrological cycle that contribute to the timing and amount of alpine river discharge during the snow-melt season (Beniston, 2006). As a result of the declining snow reservoir, earlier snow melt and a general decrease in summer precipitation, longer periods of low river flow may be observed in late summer and early autumn in many parts of Europe.

Hisdal *et al.* (2001) maintain that there is no evidence that river flow droughts have generally increased in frequency or severity over Europe in the last few decades. Nor is there conclusive proof of a general increase in summer dryness in Europe over the past 50 years due to reduced summer moisture availability (van der Schrier *et al.*, 2006). While there is no general trend across Europe, however, there have been distinct regional differences (EEA, 2008), particularly in Spain, the eastern edge of Europe and many parts of the United Kingdom, where more severe river flow droughts have been observed (Hisdal *et al.*, 2001). Yet in the latter, there is no evidence of a significant increase in the frequency of low river flows (Hanneford and Marsh, 2006).

Climate change projections predict a shift from summer precipitation to winter precipitation, earlier and reduced snow melt due to lower storage of winter precipitation as snow and less glacial melt water, leading to an overall decrease in summer runoff in the Alps (EEA, 2009a, Chapter 5). The sectors that are likely to be most affected are: agriculture (increased demand for irrigation); energy (reduced hydropower potential and availability of cooling water); health (reduced water quality); recreation (water-related tourism); fisheries; navigation; and biodiversity (EEA, 2007). The dominant impacts by region are: flooding in central Europe; hydropower, health and ecosystems in northern Europe; and water scarcity in southern Europe (EEA, 2007). Climate change is also likely to exacerbate conflicts between drinking water supply, energy production, agriculture and artificial snow production (EEA, 2009a).

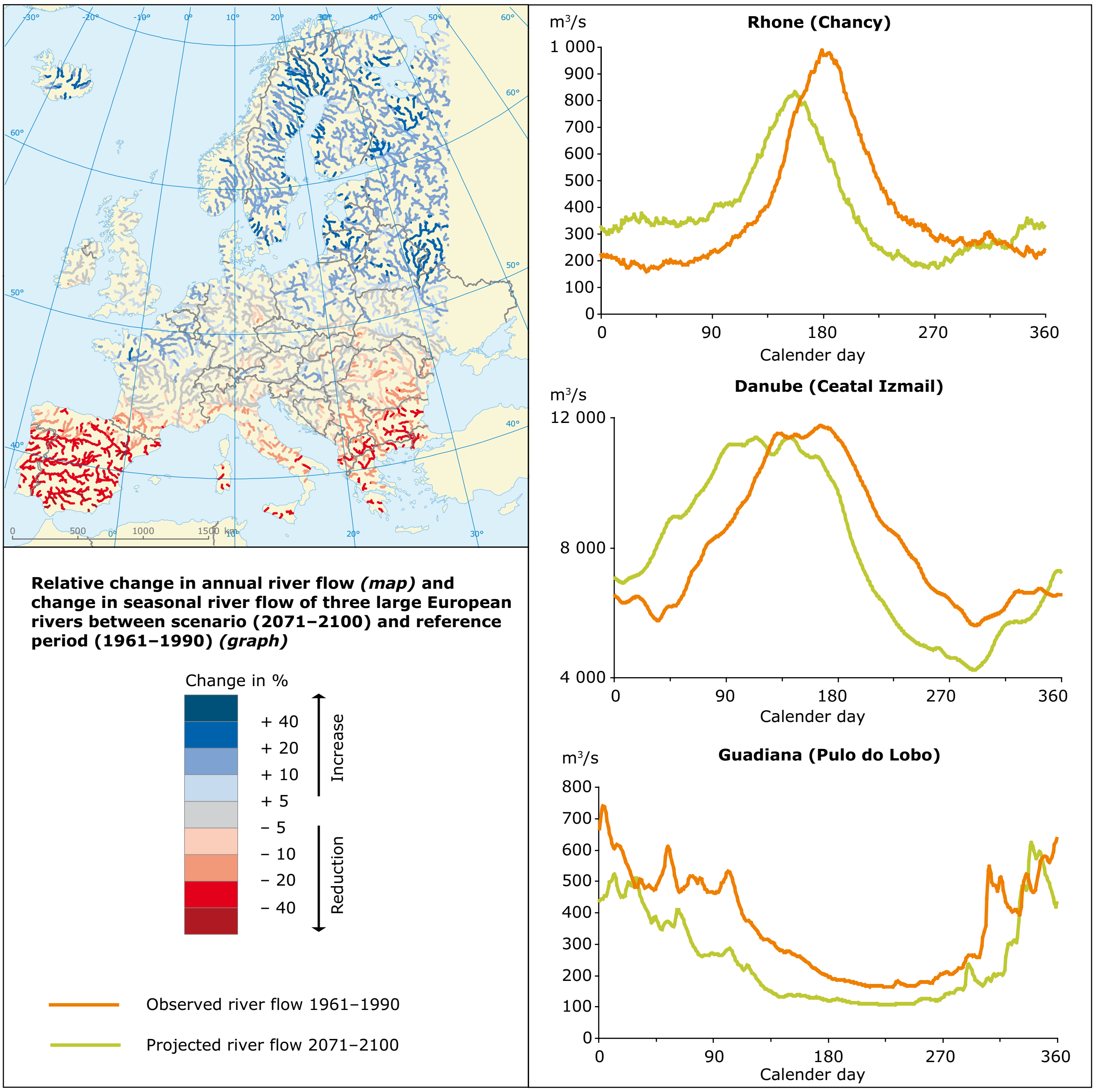
6.6.3 Impacts of heatwaves

The heatwave conditions experienced during 2003 accord with climate change projections for Central Europe for summers in the second half of the 21st century (Alcamo *et al.*, 2007). During this heat wave, the NADUF stations downstream from Swiss lakes observed variations in oxygen content levels that had never been seen before, even during the

Figure 6.9 Relative change in river flows between scenario (2071–2100) and reference period (1961–1990) (a) annual river flow and (b) seasonal river flow of three large European rivers

(a)

(b) Projected river flow 2071–2100 (green line) and the observed river flow 1961–1990 (orange line)



Relative change in annual river flow *(map)* and change in seasonal river flow of three large European rivers between scenario (2071–2100) and reference period (1961–1990) *(graph)*

Source: EEA/JRC/WHO, 2008.

drought year of 1976. This effect is accentuated by slow-flowing river water, which does not maintain a balanced exchange with atmospheric oxygen (Spreafico and Weingartner, 2005). Heatwaves since 2003 have dried up several springs in Savoy, threatening cattle farming productivity in the region (de Jong *et al.*, 2008). Whereas local water supply from springs was formerly sufficient for local populations, some regions of Savoy are now primarily experiencing water demand problems, exacerbated by a combination of supply limitation due to community expansion, influx of tourists and climate change impacts (EEA, 2009a).

6.7 Future challenges and opportunities

It is globally recognised that sustainable and appropriate solutions for water resources must jointly consider both mountain regions and the lowland regions, which are dependent on their good management. The contrasting conditions upstream and downstream need to be addressed, as well as the different demands of rural and urban areas and sectors such as agriculture, industry and domestic supply (Mountain Agenda, 2000). Climate change may worsen current water resource issues and lead to increased risk of conflicts between users both in the Alpine region (particularly the south) and outside the Alps where the incidence of droughts is likely to increase (EEA, 2009a). The International Commission for the Protection of the Rhine and International Commission for the Protection of the Danube River are critical in this regard. Recent extreme events, such as the heatwave of 2003, have 'raised national and community awareness of the need to develop adaptation strategies' (EEA, 2009a). Human pressures are at the point where the aquatic systems of the continent can no longer be viewed as being controlled by natural processes only (Meybeck, 2003). Consequently, future management of river systems should consider long-term anthropogenic impacts on the hydrological system, such as river damming, large-scale water transfers and expanding irrigation, as these all result in a general decrease of river flow quantities, coupled with increasing water quality problems (Weingartner *et al.*, 2007).

Basin-wide scenarios and projections of water resource availability are useful tools for identifying potential future conflicts and supporting joint decision-making (EEA, 2009a; Gooch and Stålnacke, 2010; Box 6.7). Unfortunately, knowledge transfer from national to regional level is often disconnected, and improvements need to be made to regional adaptation processes, as the sharing of information and active communication is fundamental when addressing uncertainty, requiring substantial cooperation between scientists, policy-makers and stakeholders. Forthcoming challenges include how to embed climate change adaptation into the management of water resources. Despite remaining uncertainties regarding the extent of changes to precipitation levels in specific locations, enough is known to start taking action (EEA, 2009a).

So far, only a few countries have overall national policy frameworks in place on climate change adaptation. In the water sector, initiatives include: long-term planning and policy-oriented research; institutional development; technical investments; spatial planning and regulatory measures; flood defence and management in response to observed trends; coastal defence; and management of water scarcity. Management plans need to consider existing or potential conflict over water resources and their usage in relation to rivers and lakes both upstream and downstream, and conflicts in the same place among different users or over time between uses (e.g. between fishing and recreation, or biodiversity) (Kennedy *et al.*, 2009). Consequently, appropriate and timely inclusion of relevant stakeholders is an important consideration.

Box 6.7 Mountain rivers in northern Sweden as a natural resource — the need for an integrated landscape approach

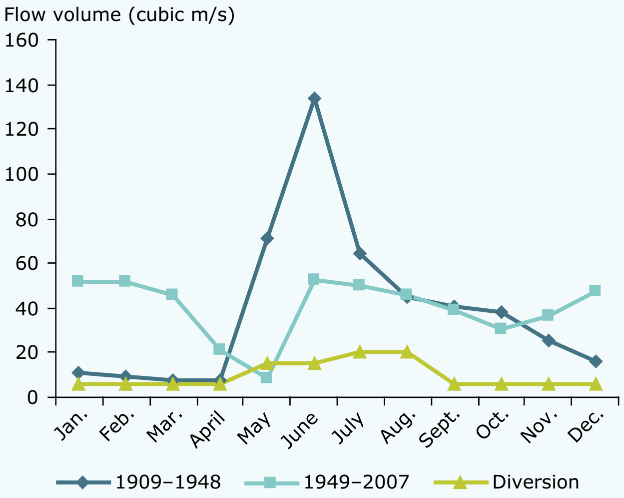
Running from the Scandinavian Mountains to the Baltic Sea, northern Sweden's rivers were modified to transport wood from the late 19th century, and later regulated to produce electricity. Four sub-catchments have been set aside as National Rivers for conservation. However, EU and national policies supported by state subsidies have revived interest for hydroelectric energy production. At the same time, nature-based tourism based on sport fishing and wilderness values is encouraged.

The catchment of the River Ångermanälven (32 000 km²), and its sub-catchment River Vojmån (3 500 km²) in Vilhelmina municipality, provide a good example of the challenge of implementing the policy statements of ecological sustainability and stakeholder participation in, for example, the Water Framework Directive and the European Landscape Convention (Angelstam *et al.*, 2009). These policy visions are consistent with the idea of a riverine landscape (e.g. Leuven and Poudevigne 2002; Selman, 2006), in which a catchment is regarded as an integrated social-ecological system with biophysical, socio-cultural and perceived dimensions. The state company Vattenfall planned to divert around 80 % of the water from one large mountain valley (River Vojmån) to another to generate more electricity. This plan led to a local debate and a referendum which stopped the river diversion.

The ecological system

Northern rivers are characterised by seasonally-dynamic flow patterns, with low flows during winter, high flows during spring snowmelt, and irregular summer and autumn peaks due to rainfall. As terrestrial biological production along the stream is often high, forests supply the stream channel with leaf litter and large amounts of dead wood that provide nutrients and morphological structure to the stream. At the catchment scale, fire-driven boreal forest dynamics make pH values fluctuate, increasing after fires and decreasing during the course of natural succession. Human fish harvests in the past were low, allowing for viable populations of migrating brown trout of large size, compared to today's rather small-sized brown trout. The diversion of water from the River Vojmån was expected to lead to a decline of over 76 % in the annual flow volume, and with a flow dynamic over the year deviating from the natural state less than from its current regulated state (Figure 6.10).

Figure 6.10 Natural (1909–1948) and recent (1949–2007) flows for the River Vojmån, and flow according to the plans for diverting water from its catchment



Source: Data from the Vojmån feasibility study.

The social system

A common proposal to encourage sustainable development is to include diverse stakeholders in governance (e.g. Sabatier *et al.*, 2005). According to the state company Vattenfall, the River Vojmån diversion plan was an attempt towards a participatory approach that aimed to include local stakeholders. Because of the heated debate that emerged, Vilhelmina municipality felt that a referendum to support the decision was needed. A 'yes' would result in starting the process of implementing the river diversion plan, and a 'no'would result in closing the project. However, there were clear inequities, and the consultation processes initiated by Vattenfall was not perceived as participatory. The 'no' side won the referendum in November 2008, with 53 % of the votes.

Implementation of sustainability and sustainable development?

An important strength of the referendum process was that all actors really cared about the ecosystem, and had a strong sense of place (Thellbro, 2006). Both sides were convinced that their arguments and suggested actions would improve the fishery and thus support Vilhelmina municipality's development as a recreation and

Box 6.7 Mountain rivers in northern Sweden as a natural resource — the need for an integrated landscape approach (cont.)

tourism destination. Table 6.2 presents an overview of strengths, weaknesses, opportunities and threats concerning the opportunity to implement the vision of ecological sustainability as a natural resource value in the catchment.

Table 6.2 Overview of strengths, weaknesses, opportunities and threats

	The ecological system	The social system
Strengths	The Vojmån sub-catchment within the large Ångermanälven catchment is the least impacted by human activity in central Sweden.	Internet was used for communication and debate; a local weekly magazine distributed to all households was used for announcements, the regional newspaper was used for debate.
Weaknesses	More than a century of stream alteration for log driving and water regulation, and cumulative effects in the terrestrial system, have had negative effects on local salmonid fish populations.	Very technical discussion about the aquatic system, and very limited understanding of cumulative effects at the scales of the river channel, the riparian zone, and the entire catchment.
Opportunities	The upper half of the catchment is ecologically intact; growing international knowledge about thresholds for assessing ecological sustainability, and about ecosystem restoration.	A local population with a strong cultural and social capital supporting local development.
Threats	Lack of funding for restoration and communication of international knowledge about reference landscapes for ecosystem restoration.	Limited understanding of the role of life modes and full-time employment in businesses and public sector vs part-time and self-employment in the process from use of landscape goods and services to landscape values.

The need for collaboration and social learning

Although the democratic process was active, knowledge about the ecosystem was limited and there were no legitimate governance arrangements with an overview of how, where, and when different actors benefit from mountain rivers. This controversy illustrates that, to implement the European Landscape Convention and the EU Water Framework Directive, an integrated landscape approach is needed including (1) knowledge production about the natural ecology of rivers and catchments, and the engineering of ecosystem restoration, and (2) collaborative learning about development based on the use of non-tangible landscape values as complements to traditional goods and ecosystem services. This requires the combination of applied natural and human science analytical approaches to work in practice with policy, governance, management and assessment of linked social-ecological systems (Angelstam *et al.*, 2009).

Source: Per Angelstam and Marine Elbakidze (School for Forest Engineers, Swedish University of Agricultural Sciences, Sweden), Johan Törnblom (Department of Physical Geography, Ivan Franko National University, Ukraine).

7 Land cover and uses

The current landscapes and land cover of Europe's mountain areas reflect major variations in biophysical characteristics and historical and recent land uses. A first set of biophysical factors that drive landscapes and land covers are those that derive from the highly diverse geology and geological histories of different parts of Europe (Ollier and Pain, 2000). There have been three major phases of mountain building in Europe: the Caledonian, approximately 500 million years ago during the Precambrian, and now represented by the Scandes (Norway and Sweden) and much of the Scottish Highlands; the Hercynian, during the younger Paleozoic (approximately 355 290 million years ago), which created the middle mountains running from the Massif Central to the Sudetes along the Czech/Polish border; and the youngest, most rugged mountains whose formation started in the Alpine era, starting about 65 million years ago and including the Alps, Apennines, Balkans, Carpathians, Dinaric Alps, the Pyrenees and other Spanish mountains, and the mountains of southeast Europe and Turkey. Some Hercynian mountains were also involved in the Alpine folding; for example, parts of the Carpathians, Corsica and Sardinia. In addition to the mountains deriving from these three major orogenies (structural deformation of the Earth's crust due to the engagement of tectonic plates), there are also more recent volcanic mountains in Europe, particularly in Iceland and Italy. The Caledonian and Alpine mountains, as well as the highest parts and north-facing slopes of the Hercynian mountains, were further modified by ice during the last glaciation. A second set of factors that define land cover derive from the great contrasts in climate from the north to south — from Arctic to Mediterranean — and from west to east: generally, from oceanic to continental. Within any one mountain range, these broad factors are further influenced by regional and local topography; examples include the dry central Alps and, at smaller scales, the ranges of microclimates resulting from variations in altitude, slope and aspect. Variation at such smaller scales is particularly important with regard to biodiversity, discussed in Chapter 8. In addition, as discussed in Chapter 8, changes in climate since the glacial period have also influenced the subsequent distribution of species in all of Europe's mountains as it has been possible for species to move upwards and northwards as the ice retreated.

While geology, geological and glacial histories, and climate have shaped the topography and influence the types of vegetation that can live on Europe's mountains, their current land cover also reflect the activities of people — and their grazing animals — in these mountains. The mountains of the Mediterranean have been used by people for over four millennia (McNeill, 1992), initially with agriculture on upland plateaus in Turkey and probably some summer grazing more widely. From about 500 BC to AD 500, significant deforestation, and subsequent erosion, took place in the Mediterranean mountains. The outcomes of this period are reflected in today's vegetation. In other parts of Europe, people gradually moved into the mountains as the climate improved, first to graze their animals in summer (often using fire to clear higher vegetation and improve grazing) and then, where possible, to grow crops. Equally, mountain forests were cut down for local or regional use and, depending on demand and possibilities of access, for export. In more recent centuries, large-scale political, economic and social changes — most recently those following the end of the socialist era around the beginning of the 1990s — have had profound effects on land cover. In summary, the land cover of Europe's mountains comprises largely cultural landscapes, reflecting a series of complex and interacting factors over the timescales of both geological and human history.

The main sources of data used to describe current and recent land covers are the Corine (CO-oRdination of Information on the Environment) Land Cover (CLC) datasets for 1990, 2000 and 2006. These datasets have been derived from satellite images; 44 different land-cover classes have been identified (Heymann *et al.*, 1994; Bossard *et al.*, 2000; Feranec *et al.*, 2007; Buttner *et al.*, 2004). The European coverage of CLC2000 includes more countries than CLC1990 and therefore land-cover changes (5 ha MMU — Minimal Mapping Unit) are not available for all countries participating in

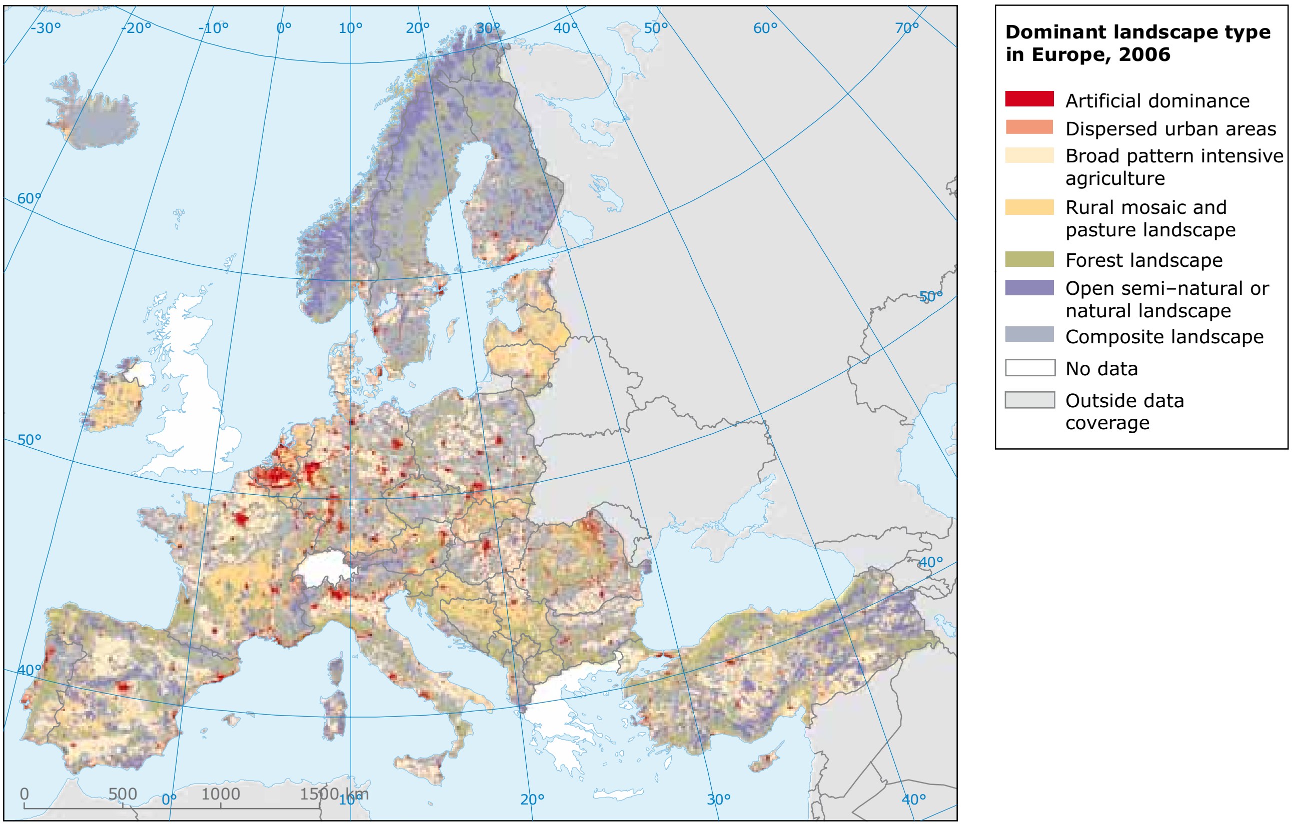
CLC2000. It should be noted that, unfortunately, the CLC2006 dataset does not include data for Greece, Switzerland or the United Kingdom, so in this chapter and in all other sections of this report where 2006 data are presented or used for comparison, these countries are not included.

7.1 Dominant landscape types

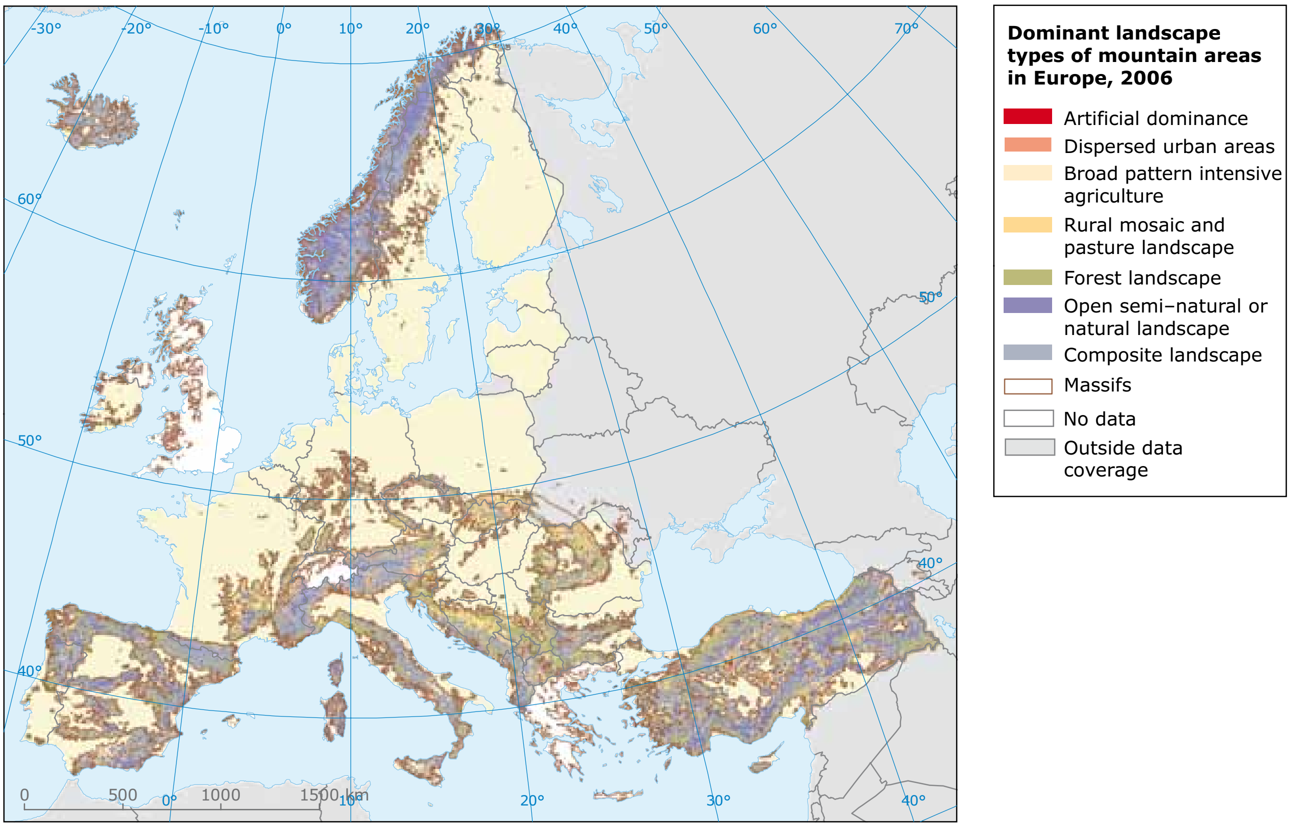
To provide an overall evaluation of the characteristics of the landscapes of Europe's mountain areas, Maps 7.1 and 7.2 present, first, dominant landscape types for all of Europe, and second, the landscape types within massifs only. These maps have been produced from a spatial modeling technique based on the CLC2006 dataset and the CORILIS (CORIne LISage) approach to Mapping (Páramo and Arévalo, 2008). A 10 km smoothing radius has been applied to five aggregated CLC classes: urban/artificial, intensive agriculture, pastures/mosaics, forests, and semi-natural/natural land. The dominant character has been assigned according to the rankings of the CORILIS values in each cell.

A comparison of Maps 7.1 and 7.2 clearly shows that the mountains of the Nordic countries contain the majority of the open semi-natural or natural landscapes of these countries, and that much of the remainder of the landscape is a composite landscape (with high proportions of non-vegetated land). Such open landscapes also cover an important proportion of mountains in other parts of Europe, including the Iberian Peninsula and Turkey. These latter areas also have considerable proportions of forested landscape, as do most other mountain ranges outside northern Europe. Artificially dominated landscapes are almost exclusively outside mountains, though many extend to their margins; as noted in European Commission (2004), the flat land immediately adjacent to mountain areas is some of the most densely populated in Europe. Similarly, in some parts of Europe, such as Spain and the mainland of Italy, there is a clear boundary at the edge of the mountains between intensive agriculture on the plains and forest and other landscape types in the mountains. However, this is not as clear-cut in other parts of Europe.

Map 7.1 Dominant landscape types in Europe, 2006



Map 7.2 Dominant landscape types in mountain areas of Europe, 2006



7.2 Land cover in mountain areas

In order to present and analyse land covers at the European, massif and national levels, the 44 CLC land-cover classes in the CLC2006 dataset have been grouped into eight broader classes (Figure 7.1 and Table 7.1). At the scale of massifs, the proportions of different land-cover types vary considerably in different parts of Europe. Again, it should be noted that values for the Alps do not include data for Switzerland; those for the Balkans/South-east Europe do not include Greece; and those for the British Isles do not include the United Kingdom. These missing data probably do not significantly affect the conclusions presented below for the two former massifs; since the majority of the mountains of the British Isles are in the United Kingdom, this massif is not further discussed here. Overall, the dominance of forests is clear in that they cover 41 % of the total area of Europe's mountains. Taking the European mountains as a whole, the greatest proportions of forests are in the mountains of Turkey (21 %), the Balkans/South-east Europe (16 %) and the Nordic mountains (14 %). At the scale of individual massifs (Table 7.1), there are particularly high proportions of forests in the Carpathians (62 %), the central European middle mountains (1: 60 %; 2: 51 %), the Balkans/South-east Europe (59 %), and the Alps and Pyrenees (both 52 %). There is only one large massif where forests are not the most widespread land-cover type: the Nordic mountains, where forests occupy 31 % of the area, but open space with little or no vegetation covers 34 %.

Looking at Europe as a whole, after forests, three land-cover types occur at similar frequencies: pastures and mosaic farmland (16 %), natural grassland, heathland and sclerophylous vegetation (15 %), and open space with little or no vegetation (14 %). The largest area of pastures and mosaic farmland is in the mountains of Turkey (31 %), followed by the Balkans/South-east Europe (15 %) and the Carpathians, French/Swiss middle mountains and the Alps (7–8 %), and, at the scale of individual massifs, there are particularly high proportions in the French/Swiss middle mountains (38 %), the central European middle mountains (2: 27 %; 1: 21 %), the Balkans/South-east Europe (22 %), and the Carpathians (21 %). For natural grassland, heathland and sclerophylous vegetation, in Europe as a whole, the greatest area is found in the Nordic mountains (mainly grassland and heathland: 29 %), followed by the mountains of Turkey (26 %) and the Iberian mountains (18 %). At the scale of individual massifs, there are particularly high proportions in the Atlantic islands (49 %), the western and eastern Mediterranean islands (38 %, 24 %), the Nordic mountains (23 %) and the Iberian mountains (22 %). The greatest proportions of open space with little or no vegetation are found in the Nordic mountains (47 % for Europe as a whole, 34 % within the massif) and the mountains of Turkey (39 % for Europe as a whole, 20 % within the massif); for the former, this includes a significant proportion of ice- and rock-covered land; while for the latter, this is mainly land above the tree line. Finally, arable land covers 10 % of Europe's mountains; the greatest areas are to the south, in Turkey (42 %), the Iberian mountains (20 %), and the Apennines (13 %), which also has the greatest proportion at the level of the massif (27 %).

Proportions of land-cover classes in mountain areas are given for each country (Figures 7.2 and 7.3). In nearly all countries with any significant mountain area, forests are clearly the most frequent land cover, with proportions above 50 % in 17 countries; the highest being 78 % in Hungary, 67 % in Slovenia and Montenegro, 65 % in Croatia, and 64 % in Slovakia and Belgium. This not the case, however, for Norway and, particularly, Iceland, where open space with little or no vegetation is most frequent (37 %, 56 %, respectively) whilst the other Nordic countries of Finland and Sweden are also notable because they have very small proportions of pastures and mosaic farmland. It is also notable that, while forests cover the greatest area of the mountains of Turkey, the proportion (30 %) is the lowest of all countries with any significant mountain area, and four other land-cover types all have values from 14 to 20 %. A further general relationship is that pastures and mosaic farmland is the second most frequent land-cover type in most countries with the notable exceptions of the Nordic countries and Turkey, mentioned above, as well as the Mediterranean countries of Albania, Cyprus and Spain, where the proportion of natural grassland/heathland/sclerophylous vegetation is higher (24–28 % compared to 14–17 %) and Italy, where the proportion of arable land is higher (19 % compared to 15 %). It can also be seen that proportions of pastures and mosaic farmland and of arable land are also rather similar in Poland (22 %, 21 %, respectively).

A comparison of Figures 7.2 and 7.3 does not show particularly marked differences between the EU-27 and other European countries with regard to the proportions of national area within different land-cover classes. However, when the proportions of each land-cover class distributed across European mountains as a whole is compared (Figures 7.4 and 7.5), different patterns emerge. Most marked is the fact that most of the artificial surfaces in Europe's mountain areas are within EU Member States, particularly Italy (12 %), Romania (11 %), and France (10 %). Outside the EU, only Turkey has a high proportion of the European mountain land within this class: 18 %. Within the EU, both Spain and Italy are notable for high proportions of arable land/permanent crops, forests, and natural grassland/heathland/ sclerophylous vegetation: 20 %, 12 %, and 19 %; and 15 %, 9 %, and 7 %, respectively. Again, Turkey has particularly high proportions of land in these three classes: 42 %, 20 %, and 26 % respectively. In the EU, Spain has a large proportion (13 %) of pastures and mosaic farmland, as does France (10 %); and, outside the EU, Turkey (31 %). Within the vegetated class, particularly high proportions of wetlands are found in individual countries. Over half of Europe's mountain wetlands are in Norway (51 %), and high proportions are also found in Sweden (18 %) and Ireland (16 %). Over half of the area of water bodies is in the two Nordic countries of Norway (35 %) and Sweden (23 %); a further 19 % is in Turkey. Finally, the importance of largely unvegetated open space in non-EU countries is marked: two Nordic countries, Norway and Iceland, have 31 % and 12 % respectively, and Turkey 39 %. Overall, most of these countries are, not surprisingly, those with large mountain areas; and, given the fact that Turkey's mountain area is so much larger than that of any other country, it is equally unsurprising that this one country has more than 20 % of the total area within five of the eight classes, and only less than 17 % for one class: wetlands (5 %).

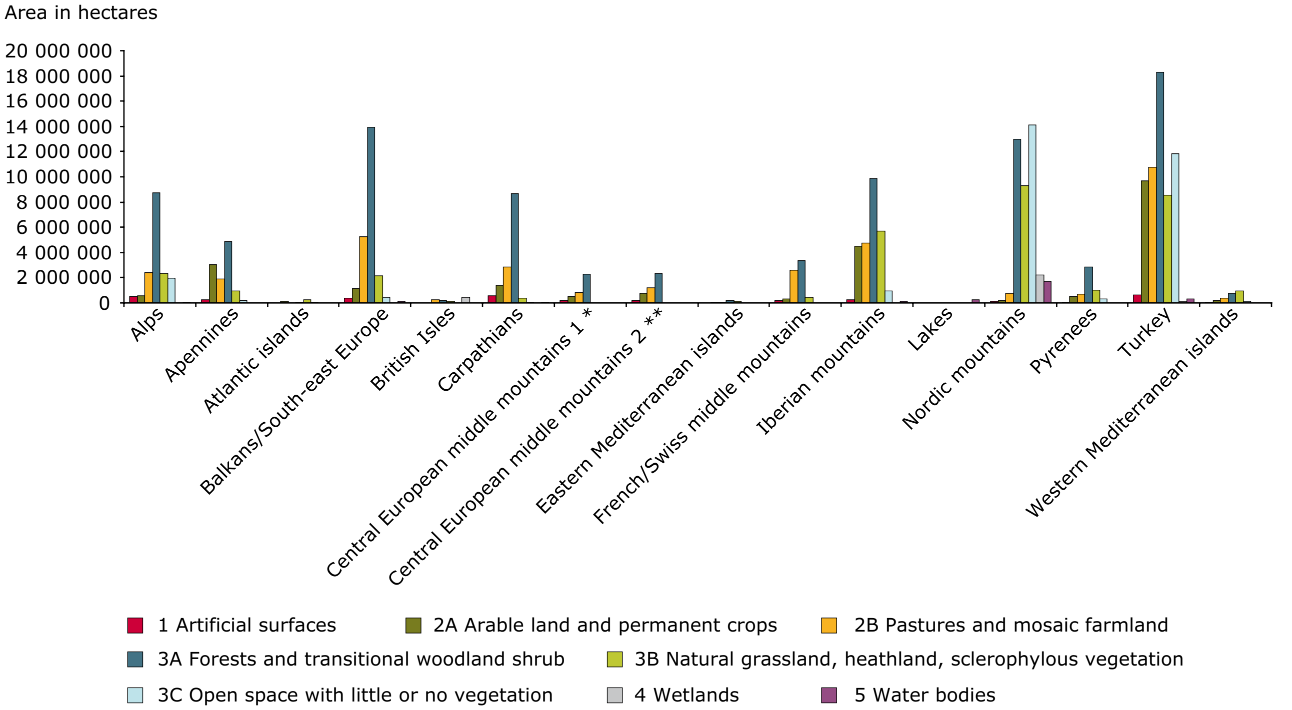
Table 7.1 Distribution of Corine land-cover classes in massifs (ha), 2006

Massif	1 Artificial surfaces	%	2A Arable land and permanent crops	%	2B Pastures and mosaic farmland	%	3A Forests and transitional woodland shrub	%	3B Natural grassland, heathland and sclero-phylous vegetation	%	3C Open space with little or no vegetation	%	4 Wetlands	%	5 Water bodies	%
Alps	527 413	3.2	571 920	3.4	2 427 726	14.5	8 733 123	52.3	2 361 275	14.1	1 976 618	11.8	26 361	0.2	88 239	0.5
Apennines	233 729	2.1	3 058 711	27.4	1 869 947	16.8	4 854 203	43.5	949 579	8.5	171 676	1.5	1 094	0.0	22 866	0.2
Atlantic islands	21 443	4.0	101 706	19.0	22 538	4.2	90 675	16.9	263 373	49.2	35 868	6.7		0.0	59	0.0
Balkans/South-east Europe	383 041	1.6	1 112 343	4.8	5 241 562	22.4	13 900 510	59.4	2 147 167	9.2	461 469	2.0	12 975	0.1	155 371	0.7
British Isles	3 851	0.4	7 872	0.8	240 435	23.6	183 905	18.0	98 630	9.7	22 127	2.2	451 363	44.3	11 736	1.2
Carpathians	544 770	3.9	1 372 629	9.9	2 850 312	20.5	8 645 546	62.3	378 291	2.7	33 143	0.2	6 843	0.0	54 283	0.4
Central European middle mountains 1 *	208 587	5.5	489 568	12.9	800 373	21.0	2 274 674	59.7	18 784	0.5	161	0.0	2 922	0.1	14 122	0.4
Central European middle mountains 2 **	199 568	4.4	758 619	16.7	1 213 579	26.8	2 315 736	51.0	25 969	0.6	413	0.0	6 562	0.1	16 254	0.4
Eastern Mediterranean islands	14 163	3.3	65 014	15.3	60 380	14.2	175 806	41.4	102 988	24.2	5 653	1.3		0.0	705	0.2
French/Swiss middle mountains	185 847	2.7	312 913	4.5	2 618 833	37.6	3 346 023	48.1	445 466	6.4	13 157	0.2	7 249	0.1	28 388	0.4
Iberian mountains	259 694	1.0	4 524 320	17.2	4 769 102	18.2	9 896 805	37.7	5 700 232	21.7	976 352	3.7	4 723	0.0	126 065	0.5
Lakes	2 562	0.9	9 899	3.4	9 953	3.4	7 062	2.4	6 619	2.3	5 729	2.0	3 291	1.1	247 860	84.6
Nordic mountains	105 713	0.3	164 371	0.4	779 569	1.9	12 989 340	31.4	9 319 801	22.5	14 136 721	34.2	2 184 786	5.3	1 690 946	4.1
Pyrenees	74 280	1.4	484 470	8.9	704 452	12.9	2 819 885	51.6	1 036 048	19.0	320 477	5.9	337	0.0	21 464	0.4
Turkey	602 821	1.0	9 673 408	16.1	10 790 899	17.9	18 308 099	30.4	8 530 922	14.2	11 825 431	19.6	126 123	0.2	329 159	0.5
Western Mediterranean islands	32 716	1.4	191 701	8.0	349 836	14.6	771 147	32.2	922 419	38.5	125 380	5.2	247	0.0	4 674	0.2
All massifs	3 400 198	1.6	22 899 464	10.5	34 749 496	15.9	89 312 539	40.9	32 307 563	14.8	30 110 375	13.8	2 834 876	1.3	2 812 191	1.3

Note: * = Belgium and Germany; ** = the Czech Republic, Austria and Germany.

Source: European Environment Agency: CLC2006 and CLC classes according to the LEAC methodology (http://www.eea.europa.eu/data-and-maps/data/land-cover-accounts-leac-based-on-corine-land-cover-changes-database-1990-2000 [accessed 8 July 2010]).

Figure 7.1 Distribution of Corine land-cover classes in massifs (ha), 2006



Note: * = Belgium and Germany; ** = the Czech Republic, Austria and Germany.

Figure 7.2 Land cover classes in the mountain area of each country as a proportion of national area: EU-27 Member States with mountain areas

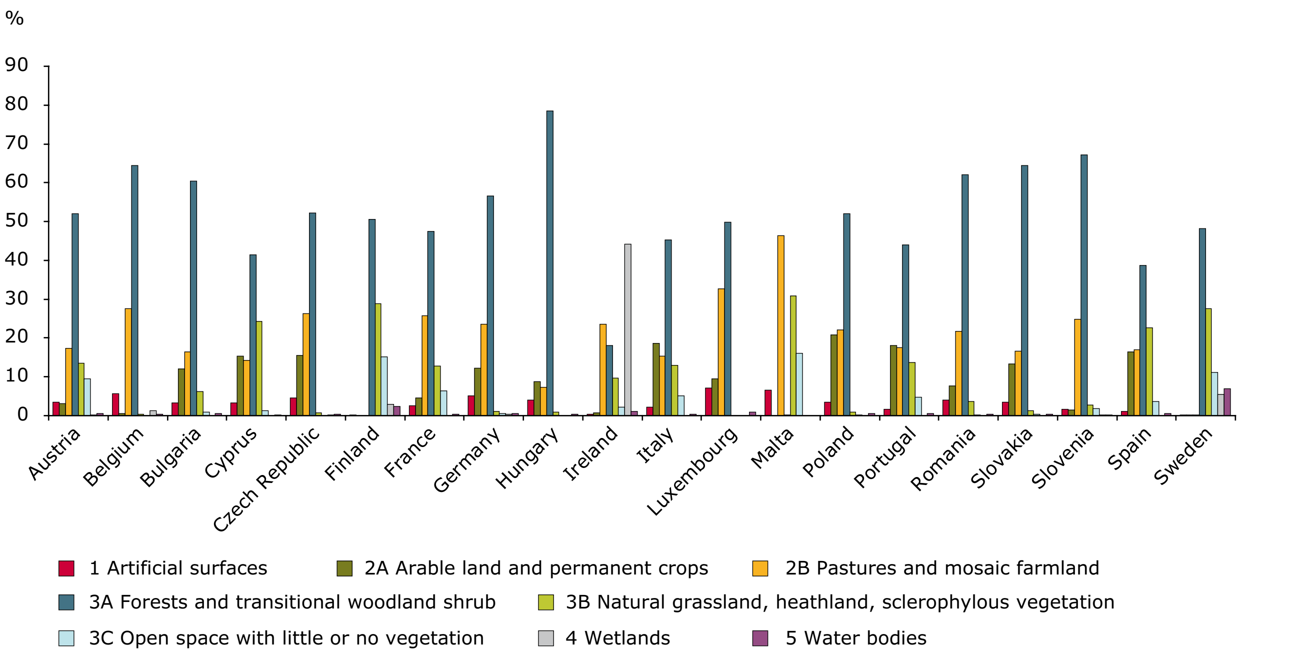


Figure 7.3 Land cover classes in the mountain area of each country as a proportion of national area: other countries

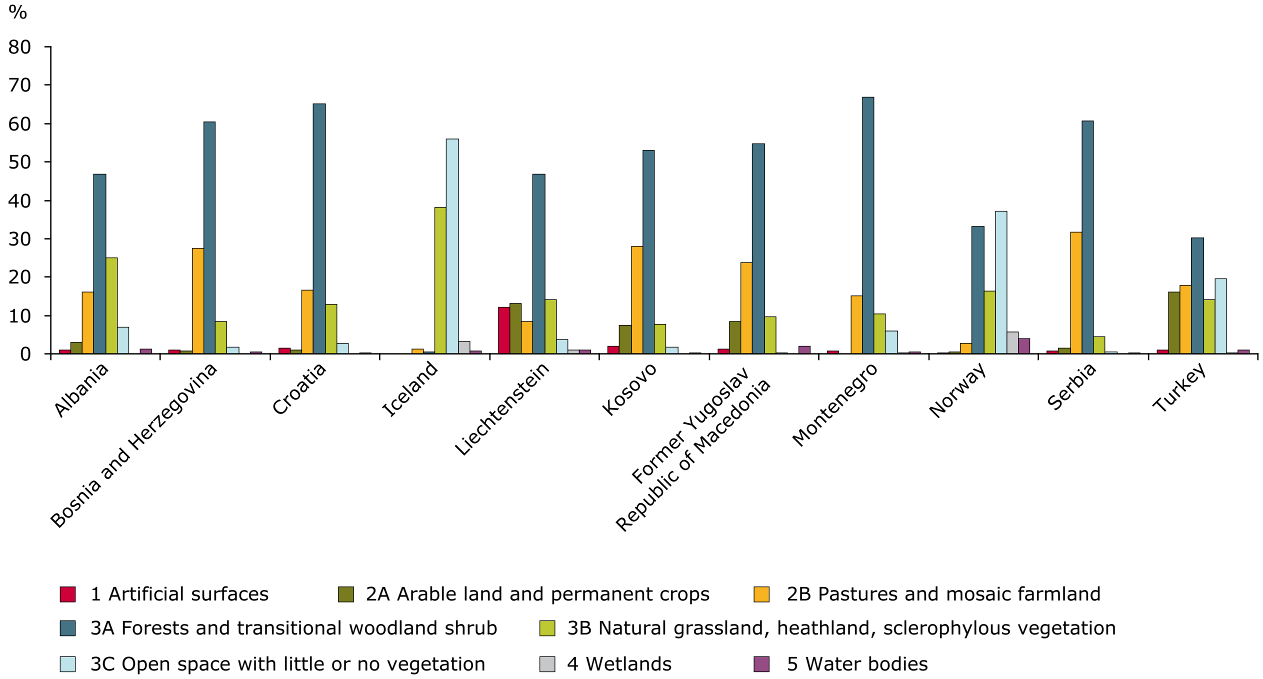


Figure 7.4 Land cover classes in the mountain area of each country as a proportion of the area of each class for all European mountains: EU-27 Member States with mountain areas

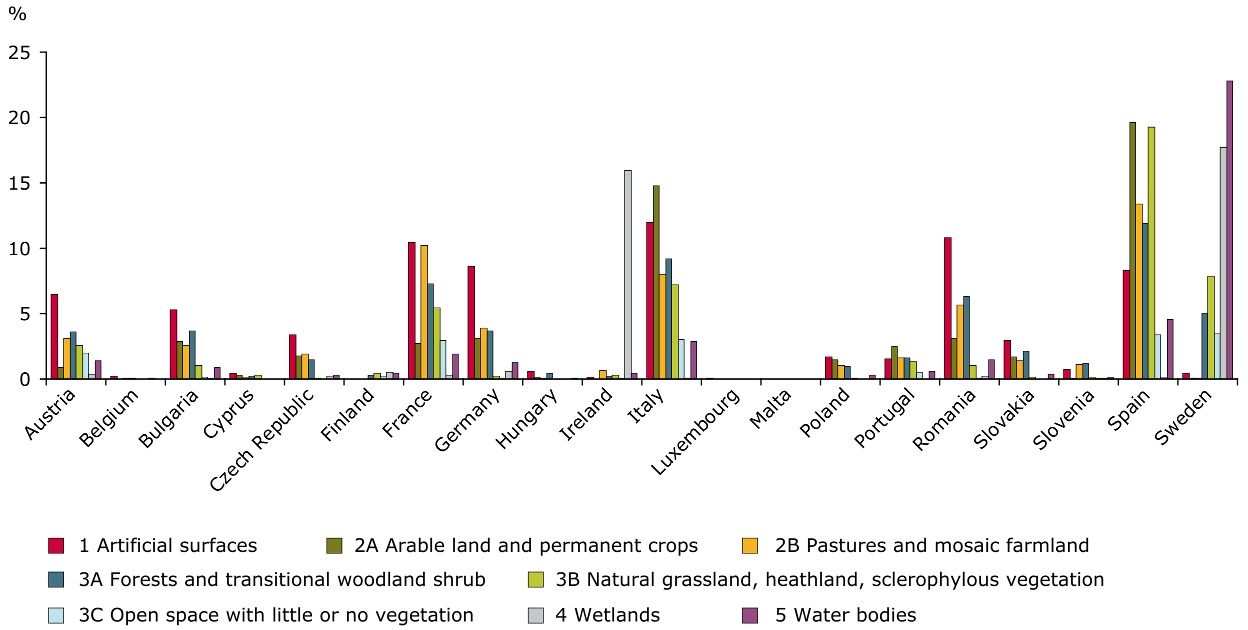
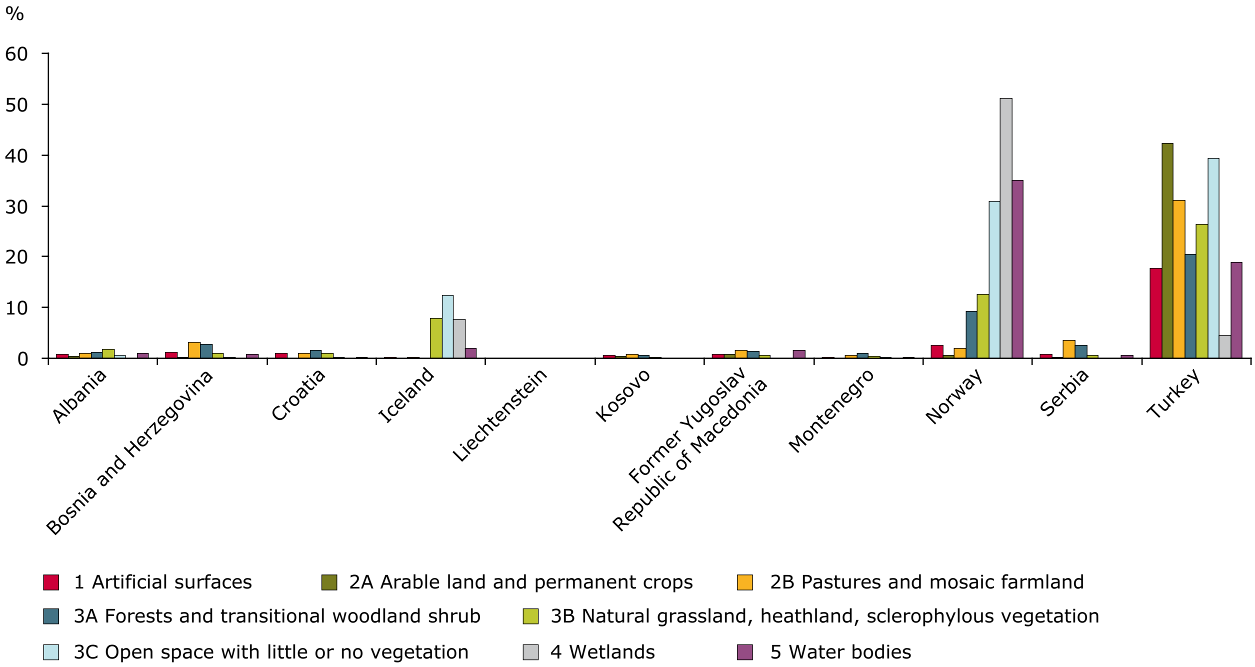


Figure 7.5 Land cover classes in the mountain area of each country as a proportion of the area of each class for all European mountains: other countries



7.3 Land cover changes in mountain massifs and countries

The distribution of land cover presented in the previous section may be regarded as a snapshot in the middle of the first decade of our century, following changes over previous centuries and millennia. To evaluate changes over the past two decades, the CLC datasets for 1990, 2000 and 2006 were used. At the first level, the five main land-cover categories are: artificial surfaces, agricultural areas, forests and semi-natural areas, wetlands, and water bodies. Between these, nine land-cover flows (LCFs) have been defined:

- LCF1: Urban land management
- LCF2: Urban residential sprawl
- LCF3: Sprawl of economic sites and infrastructures
- LCF4: Agriculture internal conversions
- LCF5: Conversion from forested & natural land to agriculture
- LCF6: Withdrawal of farming
- LCF7: Forest creation and management
- LCF8: Water body creation and management
- LCF9: Changes of land cover due to natural and multiple causes

Table 7.2 shows both the availability of data and percentage changes in land cover for the massifs from 1990 to 2000 and from 2000 to 2006. Notably, changes in the mountains of the British Isles cannot be analysed for either period; nor can changes in the Nordic mountains or the mountains of Turkey for 1990 to 2000. The value of evaluations of changes in the eastern Mediterranean islands is also limited by the lack of data for Greece in the CLC2006 dataset. In addition, it is important to note that the actual time period between the 1990 and 2000 datasets differs from one country to another. For 2000–2006, the time elapsed is more regular across countries, always being five or six years except for Albania, Bosnia and Herzegovina, and the former Yugoslav Republic of Macedonia.

As shown in Table 7.2, and taking into consideration the caveats mentioned above, the massifs undergoing the largest changes between 1990 and 2000 were the central European middle mountains 2 (6.33 %), the Iberian mountains (5.38 %), western Mediterranean islands (3.04 %) and the Pyrenees (2.98 %). There are similar trends for 2000–2006, i.e. the largest changes are observed in the Iberian mountains (2.55 %), central European middle mountains 2 (1.44 %) and the Pyrenees (1.11 %). Tables 7.3 and 7.4 provide more detail regarding the relative contribution of the different LCFs to these overall changes in land cover, and examples are presented for the Carpathians (Poland, Slovakia, Ukraine) in Box 7.1 and the Basque Country, Spain, in Box 7.2.

Table 7.2 Changes 1990–2000 and 2000–2006 (% of the first year), by massif

Massif	Changes 1990–2000		Changes 2000–2006	
	% no data	% changes	% no data	% changes
Alps	13	0.87	13	0.31
Apennines	0	1.04	0	0.57
Atlantic islands	34	0.35	34	0.45
Balkans/South-east Europe	29	0.82	26	0.52
British Isles	86	3.19	86	0.55
Carpathians	14	2.14	14	0.82
Central European middle mountains 1 *	0.6	2.00	0.6	0.48
Central European middle mountains 2 **	0	6.33	0	1.44
Eastern Mediterranean islands	25	1.18	76	0.85
French/Swiss middle mountains	13	1.14	13	0.46
Iberian mountains	0	5.38	0	2.55
Nordic mountains	100	–	0	0.68
Pyrenees	0.4	2.98	0.4	1.11
Turkey	100	–	0	0.35
Western Mediterranean islands	0	3.04	0	0.71

Note: * = Belgium and Germany; ** = the Czech Republic, Austria and Germany.
No data means that parts of the mountain massif are not covered by CLC data in one or both years.

Source: Based on EEA datasets (CLC1990–2000–2006). www.eea.europa.eu/data-and-maps/data/corine-land-cover-1990-2000; www.eea.europa.eu/data-and-maps/data/corine-land-cover-2000-2006.

Table 7.3 Contribution of each land-cover flow to the total change between 1990 and 2000 per massif (in %)

Massif	LCF1	LCF2	LCF3	LCF4	LCF5	LCF6	LCF7	LCF8	LCF9
Alps	0.46	7.03	3.98	3.09	1.57	4.73	64.94	0.13	14.07
Apennines	0.26	7.66	4.11	11.11	5.24	19.51	46.05	0.85	5.20
Atlantic islands	0.00	34.94	9.16	14.87	33.19	0.21	7.63	0.00	0.00
Balkans/South-east Europe	0.24	0.68	6.49	5.87	3.37	1.22	70.29	1.32	10.52
British Isles	0.07	0.34	0.38	2.20	0.59	1.54	94.62	0.00	0.25
Carpathians	0.06	0.53	0.63	14.05	3.03	8.55	71.91	0.62	0.61
Central European middle mountains 1 *	0.52	7.13	7.63	32.53	0.39	0.74	50.78	0.02	0.27
Central European middle mountains 2 **	0.42	1.12	1.63	64.53	0.68	1.37	29.99	0.08	0.17
Eastern Mediterranean islands	0.01	0.48	5.49	9.65	21.09	0.10	42.43	0.30	20.45
French/Swiss middle mountains	0.30	3.29	4.16	2.41	5.58	1.71	81.18	0.23	1.14
Iberian mountains	0.19	1.47	2.33	10.65	9.49	4.42	60.36	1.21	9.89
Pyrenees	0.21	1.51	2.73	5.39	0.95	2.93	60.18	0.56	25.53
Western Mediterranean islands	0.17	6.10	1.64	2.01	3.14	41.56	18.93	0.05	26.40
All massifs	0.22	2.02	2.64	14.25	5.53	5.25	61.13	0.78	8.18

Note: * = Belgium and Germany; ** = the Czech Republic, Austria and Germany.

Source: Based on EEA datasets (CLC1990–2000). www.eea.europa.eu/data-and-maps/data/corine-land-cover-1990-2000.

Table 7.4 Contribution of each land-cover flow to the total amount of change between 2000 and 2006 per massif (in %)

Massif	LCF1	LCF2	LCF3	LCF4	LCF5	LCF6	LCF7	LCF8	LCF9
Alps	0.46	3.59	10.52	0.18	0.49	0.25	58.70	0.06	25.77
Apennines	0.79	2.67	5.58	3.10	3.54	1.50	77.08	1.23	4.51
Atlantic islands	2.39	32.09	18.93	5.80	1.68	0.00	14.18	0.00	24.93
Balkans/South-east Europe	0.46	4.62	5.67	6.80	2.73	3.13	71.34	1.46	3.78
British Isles	0.04	0.74	0.58	0.58	0.08	5.36	92.62	0.00	0.00
Carpathians	0.25	0.83	1.94	8.17	0.50	3.15	85.12	0.05	0.00
Central European middle mountains 1 *	2.96	6.54	5.78	1.90	1.00	0.19	81.52	0.04	0.06
Central European middle mountains 2 **	1.12	0.99	4.99	40.25	2.57	2.39	46.60	0.88	0.22
Eastern Mediterranean islands	0.51	18.99	7.05	0.04	11.68	0.00	60.64	0.00	1.10
French/Swiss middle mountains	2.10	6.69	8.17	0.53	0.85	0.19	78.06	0.19	3.22
Iberian mountains	0.91	0.61	5.16	7.27	6.12	1.07	65.10	0.16	13.60
Nordic mountains	0.02	0.25	2.26	0.02	0.08	0.01	90.02	0.26	7.07
Pyrenees	1.22	1.26	5.26	7.97	0.69	0.18	38.91	1.01	43.51
Turkey	2.24	1.02	9.78	5.14	5.34	0.73	66.64	5.22	3.89
Western Mediterranean islands	0.32	1.52	1.91	0.20	2.69	1.30	39.43	2.78	49.85
All massifs	0.86	1.59	5.23	6.28	3.53	1.26	70.45	0.97	9.83

Note: * = Belgium and Germany; ** = the Czech Republic, Austria and Germany.

Source: Based on EEA datasets (CLC2000–2006). www.eea.europa.eu/data-and-maps/data/corine-land-cover-2000-2006.

Overall, 'forest creation and management' (LCF7) was the dominant land-cover flow during both time periods (Figure 7.7) and was more pronounced in 2000–2006. For the massifs for which a comparison is possible, the rates were considerably higher in 1990–2000 in the Pyrenees and slightly higher in the Alps and French–Swiss middle mountains, while the converse was true for 2000–2006 particularly in the Apennines, Carpathians and central European middle mountains and less so in the Iberian mountains. However, in the relatively little-forested mountains of the Atlantic islands, 'urban residential sprawl' (LCF2) was the dominant change in both periods, which is probably related to the impact of the tourism sector. In addition, a significant 'conversion from forested and natural land to agriculture' (LCF5) was observed in 1990–2000, which could be a consequence of more human activity. In the mountains of the western Mediterranean islands 'withdrawal of farming' (LCF6) was the major change in 1990–2000, but not in 2000–2006. A further massif where LCF7 was not the dominant change in 1990–2006 was the central European middle mountains 2: 'agricultural internal conversion' (LCF4) was the dominant change, and second in importance in 2000–2006, as discussed in Section 7.3.1 with regard to the Czech Republic. This flow was also important in central European middle mountains 1 in 1990–2000. The same analysis was performed at country level (Table 7.6), although in this case the changes were calculated on an annual basis in order to avoid the effect of time difference in data delivery.

Box 7.1 Land use and land-cover change in the Carpathians after 1989

After the political transformation of 1989, land-use and land-cover changes (LUCC) accelerated in central and eastern Europe, due particularly to profound changes in agriculture, improvements in the welfare of societies, growth in the tertiary sector, and rural to urban migration (Turnock, 2003). While local-scale studies are important for understanding fine-scale patterns and drivers of LUCC, regional-scale and cross-national studies often capture a broader range in the variability of underlying drivers, linking differences in land dynamics to differences in socioeconomics and policies. The variety of paths to market-oriented economies among Carpathian countries offers unique opportunities to isolate particular drivers of LUCC and better understand their relative importance (Hostert *et al.*, 2008; Kuemmerle *et al.*, 2007, 2008).

At the local scale, two types of LUCC were widespread (Kozak, 2009; Kuemmerle *et al.*, 2008), especially in the post-socialist period: abandonment of agricultural land leading to shrub encroachment and forest expansion; and increase of built-up areas, both around urban centres and in rural areas. These changes were studied in two communes in Poland (Szczawnica — 88 km^2, Niedźwiedź — 74 km^2) using a time series of air photographs (1977–2003; Dec *et al.*, submitted). Both communes have similar environmental conditions (elevation from 400 to 1 200 m) and population (currently approximately 7 000 inhabitants). However, as Szczawnica has been a spa since the 19th century and an important tourism centre, the employment structures differ. Also, agricultural areas partially abandoned after World War II were designated for large-scale sheep grazing between the 1950s and 1980s (Kaim, 2009).

In both communes, forested, abandoned and built-up areas have increased, and agricultural land has decreased. The higher dynamics of LUCC occurred mostly below 700 m, due to a striking increase of built-up areas; above 700 m, agricultural land abandonment and forest expansion dominated. These trends, related mostly to the declining importance of agriculture and major shifts in the employment structure, have been persistent in the Polish Carpathians for at least a century, as the forest transition began in the late 19th century (Kozak, 2010). The resulting landscape changes are well documented by visual comparisons of archive and contemporary photographs (see below).

At the regional scale, analysis of multi-temporal satellite images of approximately 18 000 km2 in the border region of Poland, Slovakia and Ukraine revealed widespread land-use change after 1989, with rates and spatial patterns differing markedly between regions and countries. Up to 15–20 % of the cropland used in socialist times was abandoned after the system change in all countries (Figure 7.9), probably as a response to the decreasing profitability of agriculture. Topography, accessibility of farmland, land-use patterns, as well as land ownership regimes during socialism and land reforms after 1989, strongly determined the spatial pattern of abandonment. For example, cropland abandonment rates in Poland were twice as high on previously collectivised land than in areas that remained private throughout socialism (Kuemmerle *et al.*, 2008; Kuemmerle *et al.*, 2009b).

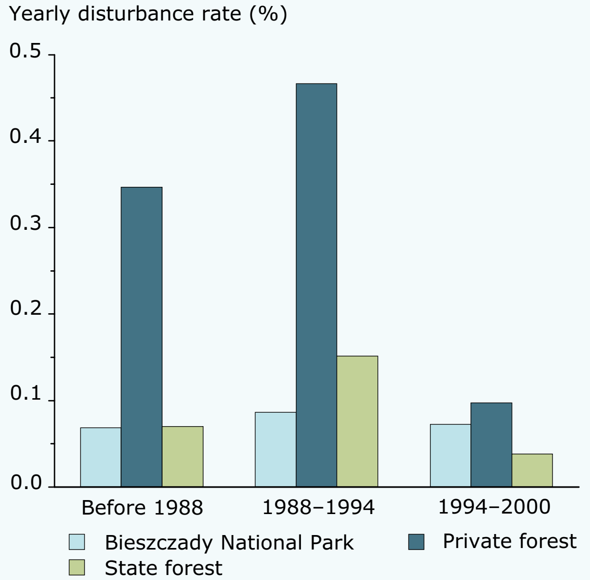
Photo: Courtesy and permission for the archive photograph: Pieniny National Park, Poland.
Landscape changes in Szczawnica as documented by the archive (left: beginning of the 20th century) and right: contemporary) photographs, 2009.

Box 7.1 Land use and land-cover change in the Carpathians after 1989 (cont.)

While the extent of forests in the Carpathians has not changed dramatically since the fall of the Iron Curtain, disturbance rates in forest ecosystems have varied between regions due to differences in forest management policies, privatisation strategies, nature protection regimes, land-use legacies, and air pollution effects (Hostert *et al.*, 2008; Kuemmerle *et al.*, 2007, 2009c; Main *et al.*, 2009). Although forest disturbance rates often increased immediately after the system change in all countries, harvesting was more widespread and forests were more fragmented in Slovakia and Ukraine than in Poland. As with land abandonment, ownership regimes were important in determining forest harvesting patterns. Forest disturbance rates in Poland were five times higher in private than in public forests (Figure 7.6).

Figure 7.6 Differences in forest disturbance rates among ownership regimes in Poland (a); clear-cut in the Ukrainian Carpathians (b); abandonment rates in the Polish, Slovak and Ukrainian parts of the study area (c); forest expansion on former cropland in the Polish Carpathians (d)

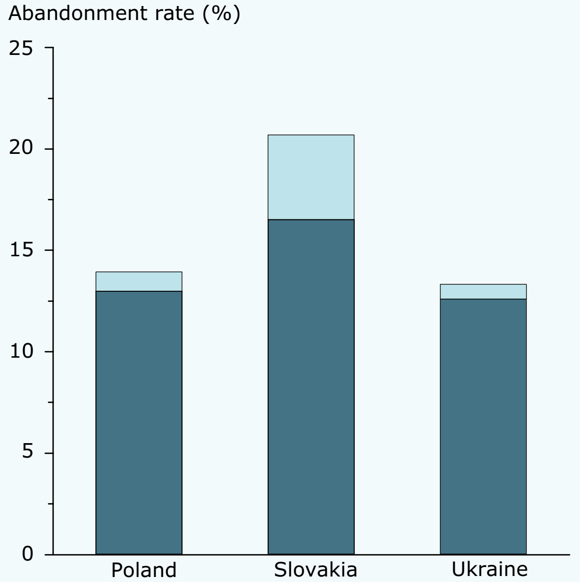
(a)



(b)

Photo: T. Kuemmerle

(c)



(d)

Photo: T. Kuemmerle

Box 7.1 Land use and land-cover change in the Carpathians after 1989 (cont.)

Yet, changes in ownership did not necessarily result in large-scale harvesting (Kuemmerle *et al.*, 2007, 2009b, c). The effectiveness of nature conservation policies also differed. For instance, forest harvesting rates dropped in Slovakia after protected areas were designated, whereas protected areas were less effective in Ukraine and much harvesting occurred just before designation. Illegal logging, widespread during the early transition years when institutions transformed and law enforcement was weak, persists in some regions (for example, Ukraine), often because of loopholes in forest legislation (Kuemmerle *et al.*, 2007, 2009a).

These local- and regional-scale studies underpin the importance of land-use related research across spatial and temporal scales, to avoid missing important socioeconomic processes that often drive environmental change in mountains. Cross-border studies further deepen understanding of policies and institutions influencing land-use and land-cover change. Ultimately, the combination of physiographic, socioeconomic and institutional analyses is an important step towards integrated mountain research with a focus on land system science (Turner *et al.*, 2008).

Source: Patrick Hostert (Geography Department, Humboldt Universität zu Berlin, Germany), Jacek Kozak, Dominik Kaim and Katarzyna Ostapowicz (Institute of Geography and Spatial Management, Jagiellonian University, Poland), Tobias Kuemmerle (Department of Forest and Wildlife Ecology, University of Wisconsin-Madison, USA), Daniel Mueller (Leibniz Institute of Agricultural Development in central and eastern Europe (IAMO), Germany).

Box 7.2 Changes in the land cover of the Basque Country, Spain

Most of the Basque Country is rural, with 85 % of the municipalities classified as mountainous; a situation that generates both limitations and potential. This rural space has a characteristic appearance: 55 % is covered by forest and 30 % by agriculture, with diverse crops. Natura 2000 sites cover 20.3 % of the area. With a population of 2 137 691 in an area of 7 224 km^2, this non-metropolitan region has one of the highest population densities (296 inhabitants/km^2) in the European Union, following transformations over the past decade. This population lives and works in only about one third of the region, in a wide littoral strip and in the valleys, because the rest is too mountainous.

The Basque Country used to be organised around central cities, industrial zones and rural centres with clearly defined functions. This structure has evolved towards a 'city-region' or 'dispersed city', as the limits of the centres have become blurred, and functions and activities have been dispersed. Everyday activities now happen in a rural/urban continuum, with no defined limits between rural and urban.

Changes in land use in the period 1966 to 2005 are shown in Table 7.5. The Basque Country is situated in the economic corridor of the European communications network, connecting the Iberian Peninsula with the rest of Europe. This strategic location involves more urbanisation and infrastructure: in the last 10 years, these areas have increased by 20.6 % to the detriment of agricultural land. This exponential development is principally due to an increase in economic activities, especially large commercial surfaces and business and industrial areas. The Basque Country also has one of the highest proportions of artificial surfaces in Spain: 5.62 % of in 2005, compared to 2.22 % for the country as a whole. Speculation in the construction industry and the development of low density residential areas are also important factors. In the near future, these trends will deepen as new highways and high-speed trains are constructed.

The usable agriculture area decreased by 5.85 %: a loss of approximately 14 000 ha. Most of this land, mainly in the valleys, has become industrial and urban zones, communication infrastructure, or forests. The primary sector is in a delicate situation: in recent decades, factors such as the low profitability of farms, changes in lifestyle and high prices for agricultural land (appropriate for other uses) have caused abandonment and meant that younger generations no longer take over farms. Agricultural activity is unappealing when urban areas offer employment relatively close to farms. Consequently, many rural areas have a residential rather than productive function; or agricultural production becomes a complement to jobs that have nothing to do with it; and there is considerable part-time agriculture. Nevertheless, urban people value local products and are conscious of their importance in terms of identity and landscape. The challenges are particularly to adapt the productive and distribution sector to emerging demands, i.e. producing sustainable quality products and selling them by short-cycle marketing.

Box 7.2 Changes in the land cover of the Basque Country, Spain (cont.)

The forest area increased by 1.7 % from 1996 to 2005. Deciduous forest increased while coniferous cover decreased slightly; they respectively account for 50.5 % and 49.5 % of the forested area. On the Cantabrian slope, forests are mainly private short-cycle plantations of *Pinus radiata*, managed by final felling and subsequent reforestation. However, strong international competition and the effects of gales in Aquitania have caused a reduction in foreign demand for Basque forest products and have aggravated the crisis in forestry. This is reflected in decreases in logging and the economic value of forests. Challenges to the current productive model include: the rough topography, which limits mechanisation; lack of economic viability due to high labour costs to obtain quality wood; extreme specialisation of production; small landholdings; absence of generational takeover; and associated risks such as loss of soil and disease.

Source: Arantzazu Ugarte and Eider Arrieta (IKT, Spain).

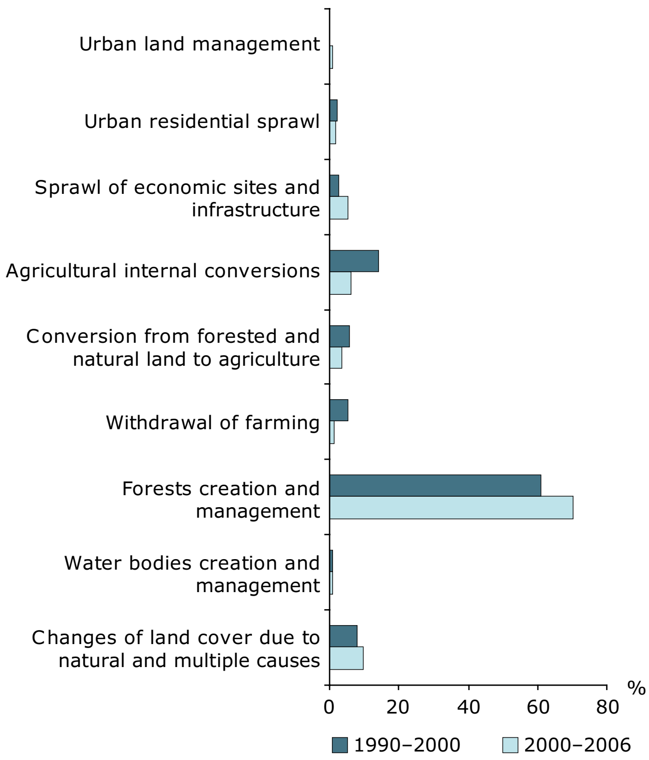
Table 7.5 Evolution of land uses in the Basque Country, Spain, 1996–2005

Land uses	Year	Area (ha)	Change %
Usable agricultural area	1996	234 246	5.85 % ↓↓
	2005	220 523	
Forest	1996	390 005	1.70 % ↑
	2005	396 701	
Urban and infrastructure	1996	33 701	20.60 % ↑↑↑
	2005	40 642	
Unproductive	1996	66 069	2.27 % ↓
	2005	64 571	
Total	1996	724 021	
	2005	722 437	

Note: Unproductive: brush, marshes, water, rocks, etc.

Source: Environmental and Territorial Planning Department of the Basque Government.

Figure 7.7 Average contribution of each land-cover flow to the total amount of change in the periods 1990–2000 and 2000–2006 in European mountain massifs



In Table 7.6, the countries with the highest percentage of land-cover changes in mountain areas (ranging from 0.3 % to 1.3 %) for the two time periods have been highlighted in grey and are discussed in Section 7.3.1. Detailed analysis of the changes in mountains at country level, differentiating between Member States of the former EU-15 and new Member States of the EU-27, is presented in Figures 7.8 and 7.9.

'Forest creation and management' and 'agricultural internal conversion' were the two main changes in the EU-15 and the new EU-27 Member States in both periods. Rates of the former were similar for both sets of Member States in both periods, but higher in the EU-15 in 1990–2000 and for the new Member States in 2000–2006. However, reflecting the differing social, economic and political trends, the changes in 'agricultural internal conversion' were considerably larger in the new Member States — especially in 1990–2000.

7.3.1 *Assessment of potential drivers of land-cover changes at country level*

The drivers of land-use change vary considerably at all spatial scales. Box 7.3 discusses these drivers for the Alps, and Box 7.4 presents the specific example of the mountains of Iceland. To assess the potential drivers of land-cover changes at country level, the six countries with the highest proportions of land-cover changes for the two time periods (Table 7.6) were selected. These countries are in

Table 7.6 Annual changes in land cover (%) in the mountains of each country: 1990–2000 and 2000–2006

Country	Annual change 1990–2000	Annual change 2000–2006
Albania	–	0.12
Austria	0.03	0.09
Belgium	0.43	0.37
Bosnia and Herzegovina	–	0.12
Bulgaria	0.09	0.07
Croatia	0.07	0.17
Cyprus	–	0.58
Czech Republic	1.29	0.44
Finland	–	0.03
France	0.13	0.08
Germany	0.19	0.07
Greece	0.19	–
Hungary	0.59	0.33
Iceland	–	0.06
Ireland	0.69	0.65
Italy	0.14	0.07
Luxembourg	0.04	0.07
Former Yugoslav Republic of Macedonia	–	0.14
Malta	0.09	0.00
Montenegro	–	0.04
Norway	–	0.09
Poland	0.10	0.08
Portugal	0.86	1.84
Romania	0.20	0.09
Serbia	–	0.05
Slovakia	0.64	0.32
Slovenia	0.02	0.02
Spain	0.30	0.25
Sweden	–	0.27
Turkey	–	0.06
United Kingdom	0.27	–

Note: Countries with the highest percentage of land-cover change are maked in grey.

Source: Based on EEA datasets (CLC1990–2000–2006). www.eea.europa.eu/data-and-maps/data/corine-land-cover-1990-2000 and www.eea.europa.eu/data-and-maps/data/corine-land-cover-2000-2006.

Figure 7.8 Distribution of land-cover changes in mountain massifs of EU-15 Member States (excluding Denmark, Finland, Netherlands, Sweden) and the new EU-27 Member States (excluding Cyprus, Estonia, Latvia, Lithuania) in 1990–2000

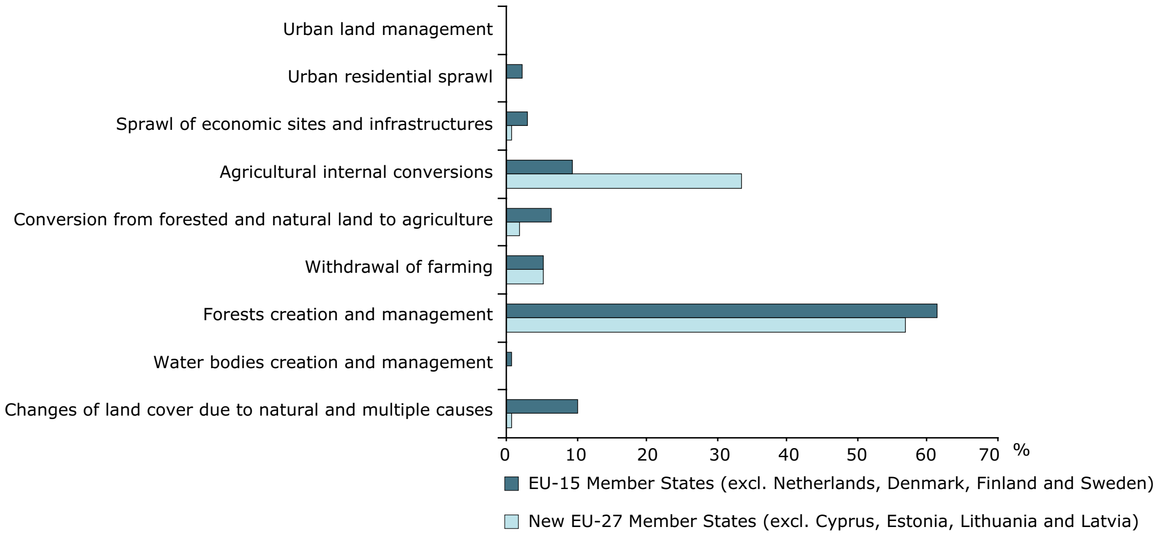
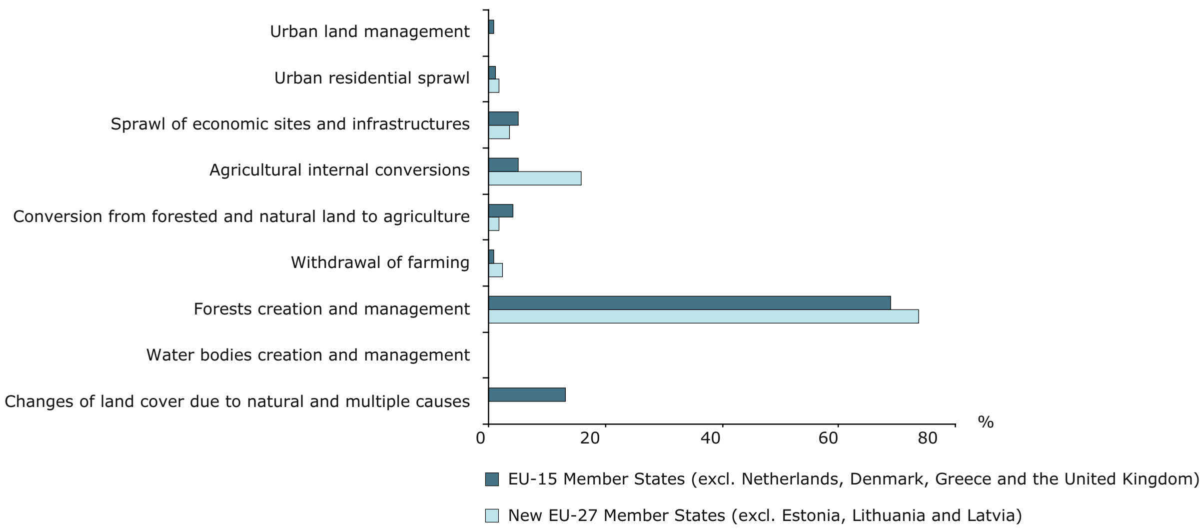


Figure 7.9 Distribution of land-cover changes in mountain massifs of EU-15 Member States (excluding Denmark, Finland, Netherlands, Sweden) and the new EU-27 Member States (excluding Cyprus, Estonia, Latvia, Lithuania) in 2000–2006



various parts of Europe, and include both EU-15 Member States (Belgium, Ireland, Portugal) and new EU-27 Member States (Czech Republic, Hungary, Slovakia). Figures 7.11 and 7.12 show the observed changes in land-cover flows.

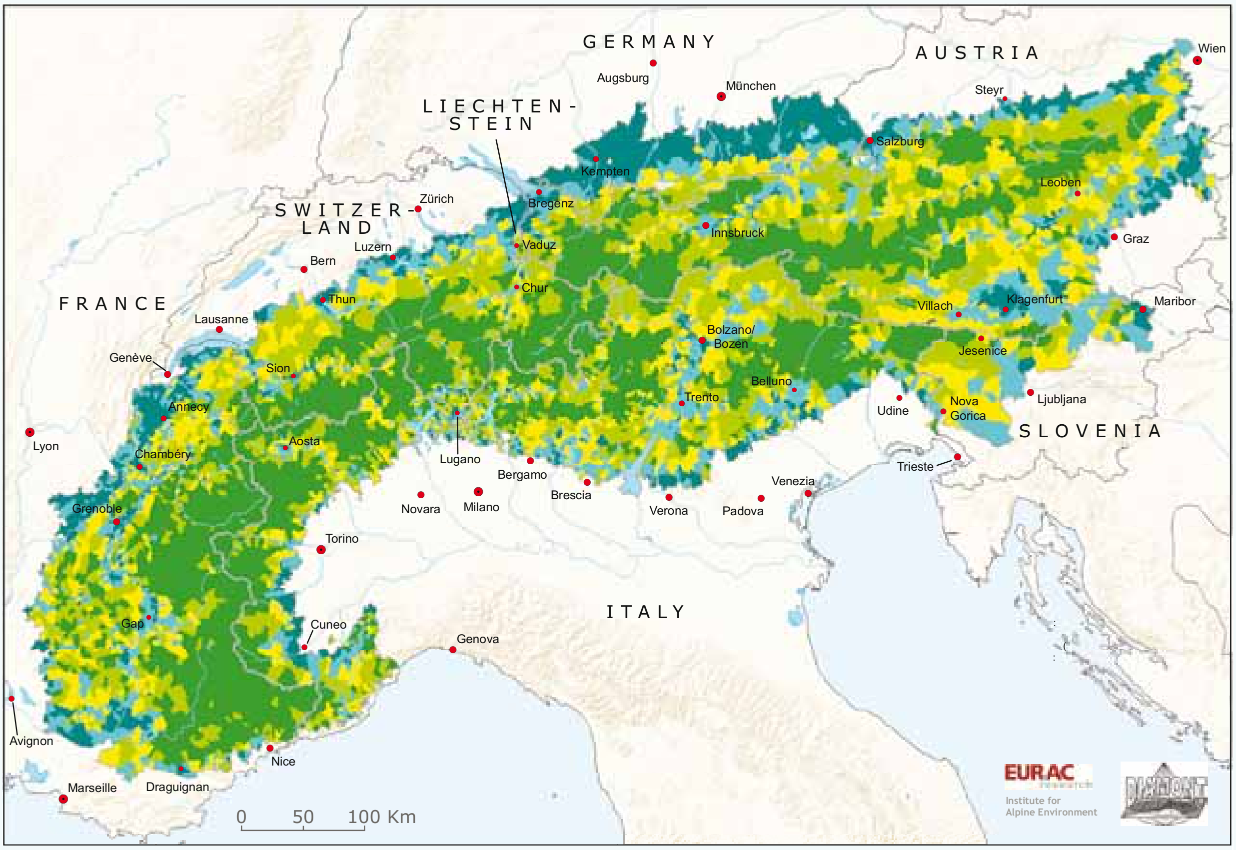
In both time periods, 'forest creation and management' is the most important land-cover flow, observed in all the countries except the Czech Republic, where 'agricultural internal land conversion' was most important. The first period, 1990–2000, was more heterogeneous, with a greater diversity of land-cover flows, than the second, when 'forest creation and management' increased in all countries — and became the only flow in the mountains of Belgium. While 'agricultural internal

Box 7.3 Land resource management and driving forces across the Alps

Compared to surrounding lowlands, the area for permanent settlement in mountain areas is limited by steep slopes, altitude, soil productivity for agriculture, and natural hazards — as well as climate extremes. In the Alps, characterised by intensive land use in the valleys related to agriculture, tourism, and industrial activities and highly populated areas, land-use conflicts are pronounced and land is a scarce resource.

While the spatial planning authorities in the Alpine states define the permanent settlement area in different ways, the challenge that the proportion of land available for economic use is less than in the lowlands prevails across the Alps. On average, about 17 % of the area identified under the Alpine Convention can be considered as appropriate for permanent settlement (Tappeiner *et al.*, 2008). While some municipalities have a permanent settlement area of less than 1 %, in others it is almost 100 %; about 16 % of municipalities have more than 50 % of their territory as permanent settlement area. Along the main ridge of the Alps, the proportion is lower than in the pre-Alpine foothills and the large valleys (Map 7.3). Population densities in some places, such as the areas around Grenoble or Annecy or around Lake Como, correspond to those of agglomerations such as Berlin, Munich or Vienna.

Map 7.3 Permanent settlement area within the Alpine Convention area



Permanent settlement area within the Alpine Convention area

Available settlement area per municipal area (%)

≤ 6.1   > 6.1–13.5   > 13.5–23.9   > 23.9–43.6   > 43.6

Source: Tappeiner *et al.*, 2008.

Box 7.3 Land resource management and driving forces across the Alps (cont.)

Available land becomes a shrinking resource even if land is not lost but converted from agricultural and forest land into built-up areas. In the German part of the Alpine Convention area, the area of settlement and transport increased by 20 % from 1992 to 2004. In the Austrian Alpine Convention area, built up land increased by about 30 000 ha from 1995 to 2004. In Switzerland, developed land increased by 6 664 ha (16 %) in the period between the census in 1979/1985 to 1992/1997 (UBA, 2004).

Driving forces for land resources

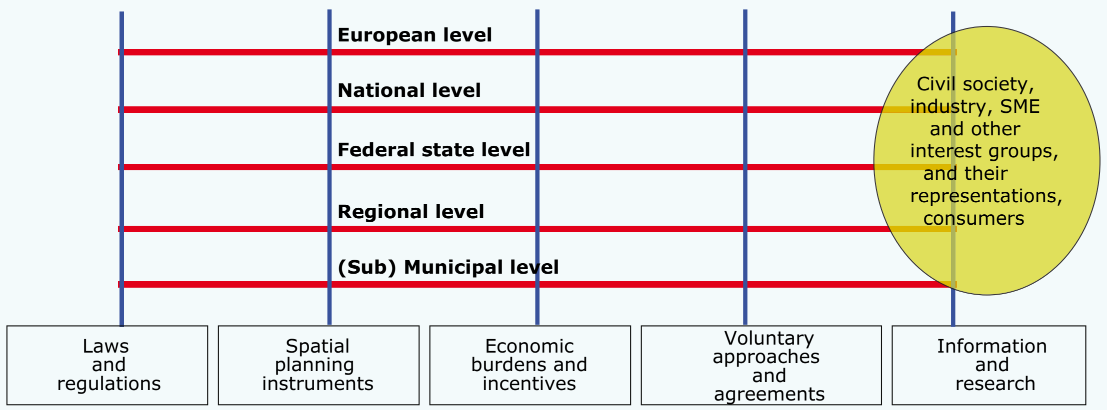
What are the main driving forces for this remarkable change of land use? Two opposing general trends can be observed: first, the abandonment of traditional agricultural areas and their related settlements in favour of easier job opportunities in services or industry; second, the concentration of economic power, labour markets and public services in the easily accessible core towns of the Alps. There are many single drivers, which may be summarised within six categories: socioeconomic and technological change; individual preferences; infrastructure policies and subsidies; spatial planning; municipal budgets and financing; and land prices and availability of brownfield sites (Hofmeister, 2005).

Each driver is embedded in different, mutually overlaying and complex cause effect relationships. Examples include the competition between municipalities for commercial investors and related tax revenues, higher private living standards combined with decreasing household sizes demanding an increase of residential area, or the functional separation of residential and working places. The latter causes growing work-related mobility and thus a demand for more land for transport infrastructure, triggering processes of sub- and peri-urbanisation. Cultural backgrounds and national differences in social security systems also play a part, as owner-occupied homes are the most common means of providing for private retirement (Helbrecht and Behring, 2002). Because of their natural assets and relatively easy accessibility in the middle of Europe, certain regions of the Alps have become destinations of European amenity migration. This phenomenon appears particularly in municipalities offering good accessibility, outstanding natural assets and a high level of services. Amenity migration is driven by soft locational factors such as landscape qualities and recreation opportunities, as well as improved commuting possibilities, which are attractive for retirees, qualified employees and service businesses alike.

How could land resources be managed in a better way?

By signing the Spatial Planning and Soil Protection Protocols to the Alpine Convention, its Contracting Parties have acknowledged that the increase in land take needs to be slowed down. The implementation of such a sustainable land resource policy requires adequate instruments. In the Alpine countries, instruments exist at different levels and in different categories (Figure 7.10); about 110 instruments influence land resource management at the regional scale (Marzelli *et al.*, 2008; DIAMONT, 2008). Policy options include urban development concepts, incentives to mobilise inner-urban plots for construction, regional pools for commercial areas and the rezoning of residential land for agriculture. Overall, challenges for sustainable land development in the Alps include an integrated view of settlement and traffic infrastructure policy, cost transparency between densified and dispersed settlement structures, and a strengthening of municipal planning responsibilities at the regional level.

Figure 7.10 Main categories of instruments for land resource management



Source: Stefan Marzelli and Florian Lintzmeyer (Ifuplan, Germany).

Box 7.4 Land-use pressures and planning in the central highlands of Iceland

Iceland's highland interior is uninhabited. Nevertheless, socioeconomic pressures are rapidly changing the character of this mountainous region. The central highlands are increasingly the subject of conflicting economic interests and divergent visions of nature. Historically, they were important as grazing commons for sheep farming communities in the lowlands — a form of land use that continues. Each rural municipality adjacent to the highlands controlled a slice of territory extending into the centre, in some places without a clear border. The municipality was responsible for managing the common grazing lands and gathering the sheep in autumn. Many individual farms also claimed parts of the territory. The ownership pattern was thus quite complicated. Under legislation passed in 1998 to clarify ownership, the national government would assume ownership wherever documented evidence could not substantiate private tenure. This led to a lengthy legal procedure, which continues. To move from rather ad hoc land-use decisions and a lack of coherent planning, in 1999, a general plan was approved for the region, and a permanent committee was set up to develop and administer it. The committee must deal with several municipalities, landowners and other involved stakeholders. Farmers, power companies, tourism operators, recreational users and conservationists all have a stake in the area. With increased diversity in land use, planning becomes more complex.

The origins of recreational travel in the highlands can be traced to new transport technology — jeeps and other four-wheel-drive vehicles introduced after World War II (Huijbens and Benediktsson, 2007). The development of the 'superjeep' in the 1980s led to greatly increased traffic in the region, which is now crisscrossed by vehicle tracks. The recent addition of quad bikes has added to the problem of off-road driving, in some places causing serious damage to vegetation. The massive increase in international tourist arrivals in Iceland in recent years has also affected the highlands. Certain destinations have become very popular and crowded in summer (Sæþórsdóttir, 2010). Trampling by hikers is a problem in several areas with highly erodible volcanic soils and delicate mossy vegetation.

Hydropower infrastructure has been expanding since the 1960s. Dams, reservoirs, large power stations, high-voltage transmission lines and service roads have changed the appearance of large tracts in the mountains of southwest Iceland. The construction of the Blanda power station in North Iceland caused the flooding of a large area and led to conflicts with farmers. Most controversial has been the building of Europe's highest dam at Kárahnjúkar in northeast Iceland in the early 2000s, and the corresponding radical changes to the natural landscapes of this remote highland area (Benediktsson, 2007). This led to a severe clash between conservationists and proponents of power-intensive industrialisation. In an attempt to resolve such conflicts, a 'Master Plan for Hydro and Geothermal Resources in Iceland' has been in preparation since 1999. Its backbone is a multi-criteria numerical assessment and ranking of all major potential sites for energy development in the country. Technical and economic feasibility, socioeconomic impacts, and impacts on tourism, recreation, farming, and the natural and cultural heritage are evaluated. Much effort has been put into developing methods for some of these complex tasks (cf. Thórhallsdóttir, 2007).

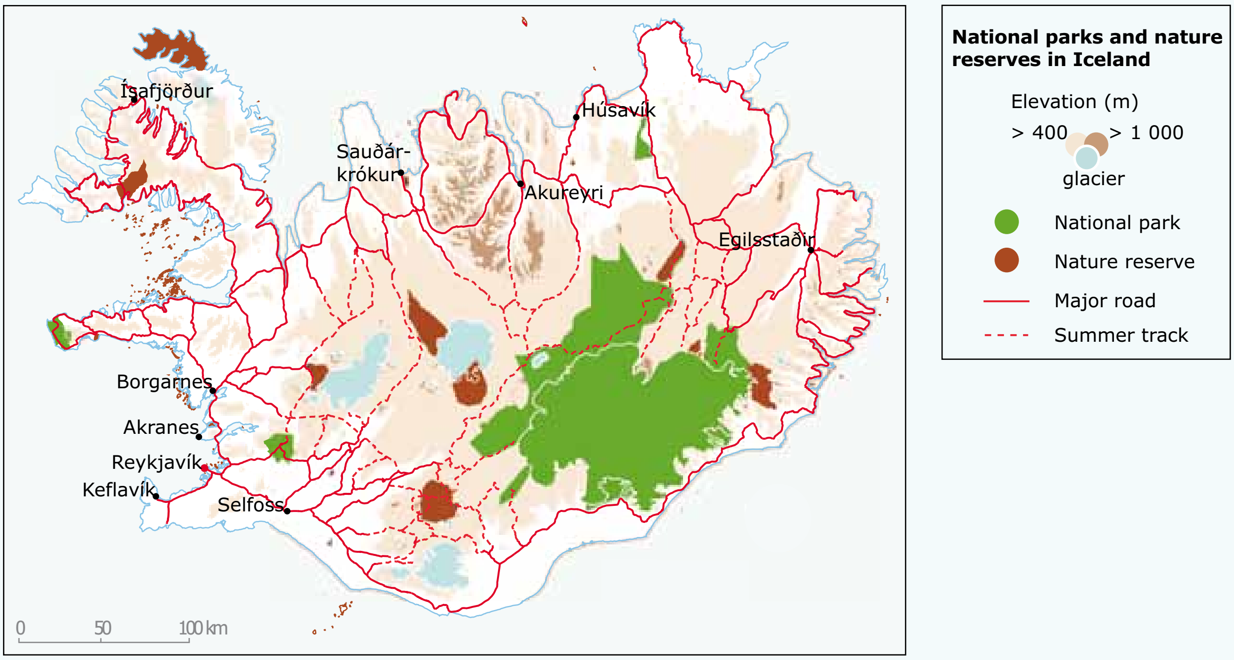
Partly in response to the controversies surrounding hydropower development, ideas of new protected areas in the central highlands gained ground during the 1990s. This led to the designation in 2008 of Vatnajökull National Park (Map 7.4), which covers 13 600 km² and is Europe's largest national park. Conservation planning for the park is under way. Rural communities adjacent to the park want to make the most of the opportunities for tourism provided by the park designation, but this has to be carefully balanced against conservation of ecosystems and landscapes in the planning process.

In early 2010, Iceland's planning legislation is under review by Parliament. The bill under discussion includes a provision for a countrywide coordination of the diverse sectoral plans and policies that affect land use. The need for careful planning in the central highland area is emphasised. If the bill is passed, this may create conditions for more orderly decisions about the uses of this vast and precious region.

Source: Karl Benediktsson (Department of Geography and Tourism, University of Iceland).

Box 7.4 Land-use pressures and planning in the central highlands of Iceland (cont.)

Map 7.4 National parks and nature reserves in Iceland



Source: Map by Karl Benediktsson, based on data from the National Land Survey of Iceland and the Environment Agency of Iceland.

Table 7.7 Distribution of the land-cover flow 'forest creation and management' among more detailed land-cover flow categories (changes in %)

	Total forest creation and management (LCF7)		Afforestation (LCF72) and conversion from transitional woodland to forest (LCF71)		Recent felling and transition (LCF74)	
	1990–2000	2000–2006	1990–2000	2000–2006	1990–2000	2000–2006
Belgium	96.8	100	52	43	36	57
Czech Republic	31.2	40	18	31	13	7
Hungary	70.1	85.4	39	7	29	66
Ireland	59.5	67.7	29	28	30	44
Portugal	69.2	80.8	29	13	37	64
Slovakia	61.8	86.4	28	14	32	75

Source: Based on EEA datasets (CLC1990–2000).
CLC2006 and CLC classes according to the LEAC methodology (http://www.eea.europa.eu/data-and-maps/data/land-cover-accounts-leac-based-on-corine-land-cover-changes-database-1990-2000 [accessed 8 July 2010]).
www.eea.europa.eu/data-and-maps/data/corine-land-cover-1990-2000; www.eea.europa.eu/data-and-maps/data/corine-land-cover-2000-2006.

Figure 7.11 Contribution of each land-cover flow to the total change per year in mountains (100 %) between 1990 and 2000 for six selected countries

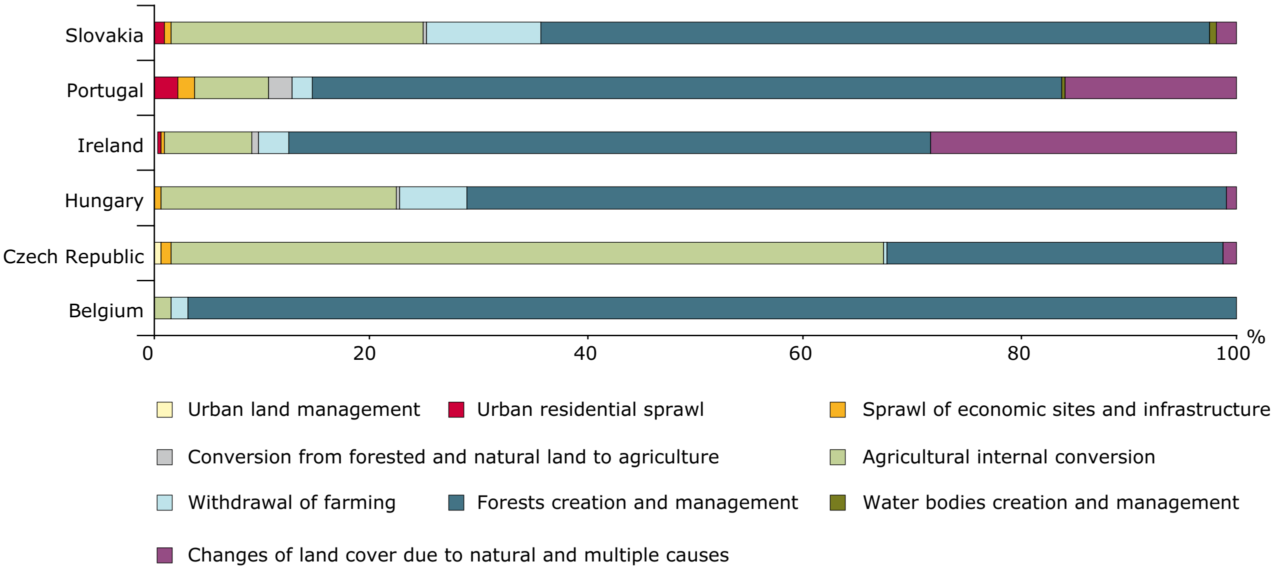
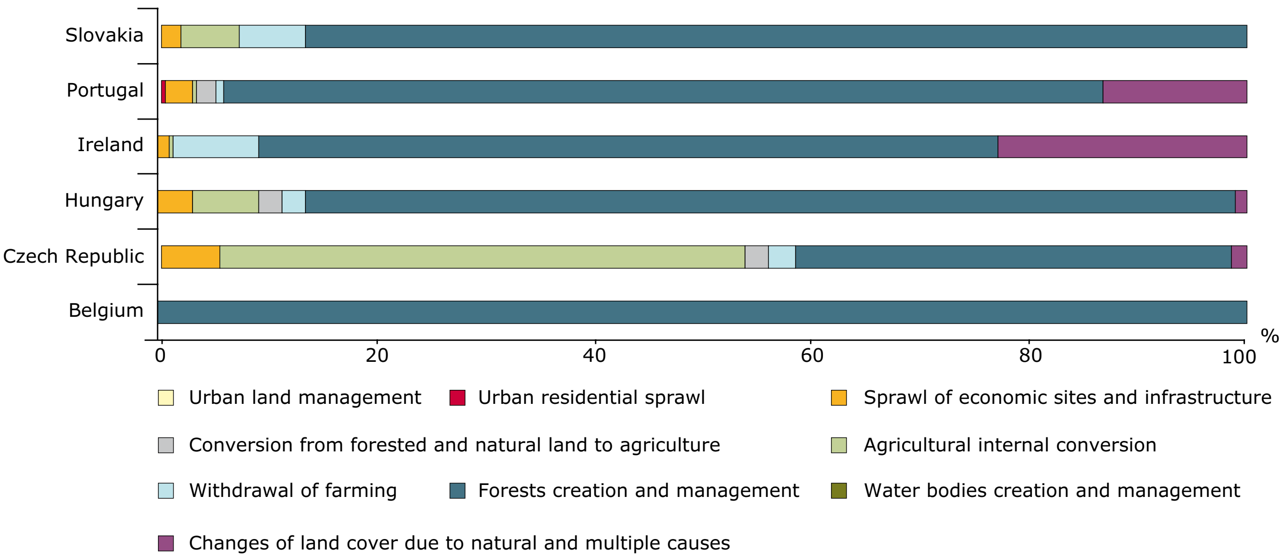


Figure 7.12 Contribution of each land-cover flow to the total change per year in mountains (100 %) between 2000 and 2006 for six selected countries



conversion' remained important in the Czech Republic in 2000–2006, it decreased from more than 20 % to less than 7 % in both Hungary and Slovakia. In order to understand the mechanisms behind these land-cover flows, further detailed analysis was done for the most common land-cover flows, including the use of additional data to explain the observed patterns.

With regard to forest creation and management, Table 7.7 shows the distribution of the land-cover flow 'forest creation and management' among more detailed land-cover flow categories. Between 1990 and 2000, the flows in Belgium, Czech Republic and Hungary were mostly due to 'afforestation and conversion from transitional woodland to forest, followed by 'recent felling and transition'. The latter category is more important in Ireland, Portugal and Slovakia. Between 2000 and 2006, 'recent felling and transition' became most important for all the selected countries except the Czech Republic.

'Agricultural internal conversion' took place mainly in the Czech Republic, Hungary and Slovakia. In the Czech Republic, most of the change was due to the extension of set-aside fallow land and pasture, as large parcels were converted from cropland to grassland. In Hungary, the same process of conversion was dominant between 1990 and 2000, but from 2000 to 2006, there was a wider range of processes. For Slovakia, there is not one particular change trend. 'Change of land cover due to natural and multiple causes' are the main flows in both Ireland and Portugal in both time periods. Most of these flows were semi-natural rotation, i.e. rotation between dry semi-natural and natural land-cover types of CLC. In Portugal, there was also some natural colonisation of land previously used for human activities, as well as forest and shrub fires.

From this analysis, the six countries can be grouped according to the land-cover changes observed. In Belgium, the dominance of 'forest creation and management' can be explained by national and regional policy. Mountains occupy a relatively small part (4.4 %) of the national area and are not the subject of any particular policy. The small area of the mountains, their low altitude (max. 694 m) and the absence of significant disadvantages in regard to the rural areas as a whole do not justify a differentiated policy initiative. Forestry is significantly more developed in the mountains than elsewhere in Belgium. In addition to producing wood, they are an essential asset for tourism, which represents the main economic activity of the area. In the Czech Republic, the changes in land cover derive from the employment structure in mountain areas, with a high proportion of employment in the primary sector, and the implementation of programmes for agriculture development in the

Box 7.5 The abandonment of vineyards in Slovakia

Agricultural areas are declining in many parts of the former socialist countries, often because socioeconomic and political changes make agriculture less profitable. The decreased profitability of viniculture and viticulture after 1989 represents a striking and negative phenomenon affecting a relatively large area of Slovakia.

The south slopes of the mountains, and partly also the lowlands, provide good conditions for the cultivation of a broad spectrum of grape varieties. *Vitis vinifera*, the common grape vine, has been grown in Slovakia since Roman times, with the first written accounts from the early 9th century. In the 16th and 17th century, all viticultural towns became free royal towns. The golden age of viticulture was the 18th century, with approximately 57 000 ha of vineyards in the current area of Slovakia in 1720: almost three times more than today. In the second half of the 19th century, fungal disease affected production severely. After the revolution in 1948, forced collectivism of agriculture brought the end of business enterprises. Each village established a farmers' association, and the Slovak viticultural cooperative society became the State Vine Factory as monopoly producer of wine. In the 1970s, Slovakia was changed by land reclamation, with a focus on quantity rather than quality.

After the Velvet revolution in 1989, the viticultural area was on the edge of self-sufficiency. The long-term process of restitution meant that many estates did not have an owner. At present, there are 22 000 ha of registered vineyards, of which 16 000 ha are managed and only 12 000 ha are productive; down from 19 000 ha in 1997, of which approximately 40 % were more than 20 years old. Current technology means that many of these vineyards will be uprooted; thousands of hectares have been abandoned. They are also economically uncompetitive in comparison to those in countries such as Australia, New Zealand, South Africa, Chile and Argentina, which have multiplied their production and export of wines to European Union. In addition, there are subsidies of EUR 7 000/ha for uprooting and abandoning vineyards, to decrease the overproduction of unsalable wine in the European Union. Finally, many owners — often the grandchildren of former wine producers, who have no interest in work in vineyards — are waiting for the reclassification of vineyards as building land, a trend strongly supported by developers. At the same time, EUR 3–5 million/year is allocated to Slovakia for the development of products, restructuring and conversion of vineyards, investment in companies and crops insurance: all essential contributions to the modernisation of viniculture and viticulture in Slovakia.

The effects of the abandonment of vineyards on biodiversity is significant, with is secondary succession heading towards several successional stages — for example, continental deciduous thickets (*Prunion spinosae* de Soó 1951) to climax forests, mainly oak hornbeam forests (*Carici pilosae—Carpinion* Issler 1931), which are found where vineyards abandoned in the 19th or the early 20th century.

Source: Robert Kanka (Institute of Landscape Ecology, Slovak Academy of Sciences, Slovakia).

country before its accession to the European Union. Forest harvesting is a major activity in mountain areas, as is tourism. For Ireland and Portugal, the importance of land-cover change due to 'natural and multiple causes' can be linked to the fact that, of these six countries, the mountains of these two countries are the least accessible (see Table 3.2). The mountains of Portugal have also experienced depopulation (Table 2.8), which could be linked to the natural colonisation of land previously used for human activities, as well as to forest fires. Finally, in Hungary and Slovakia, the contribution of 'agriculture internal conversion', especially between 1990 and 2000, was linked to changes in the importance of the agricultural sector in mountain areas as well as the implementation of national and European agriculture plans (Box 7.5). However, other driving forces behind the trends are likely to have been rather different, given that the mountain population of Hungary decreased in this period, while that of Slovakia grew (Table 2.8).

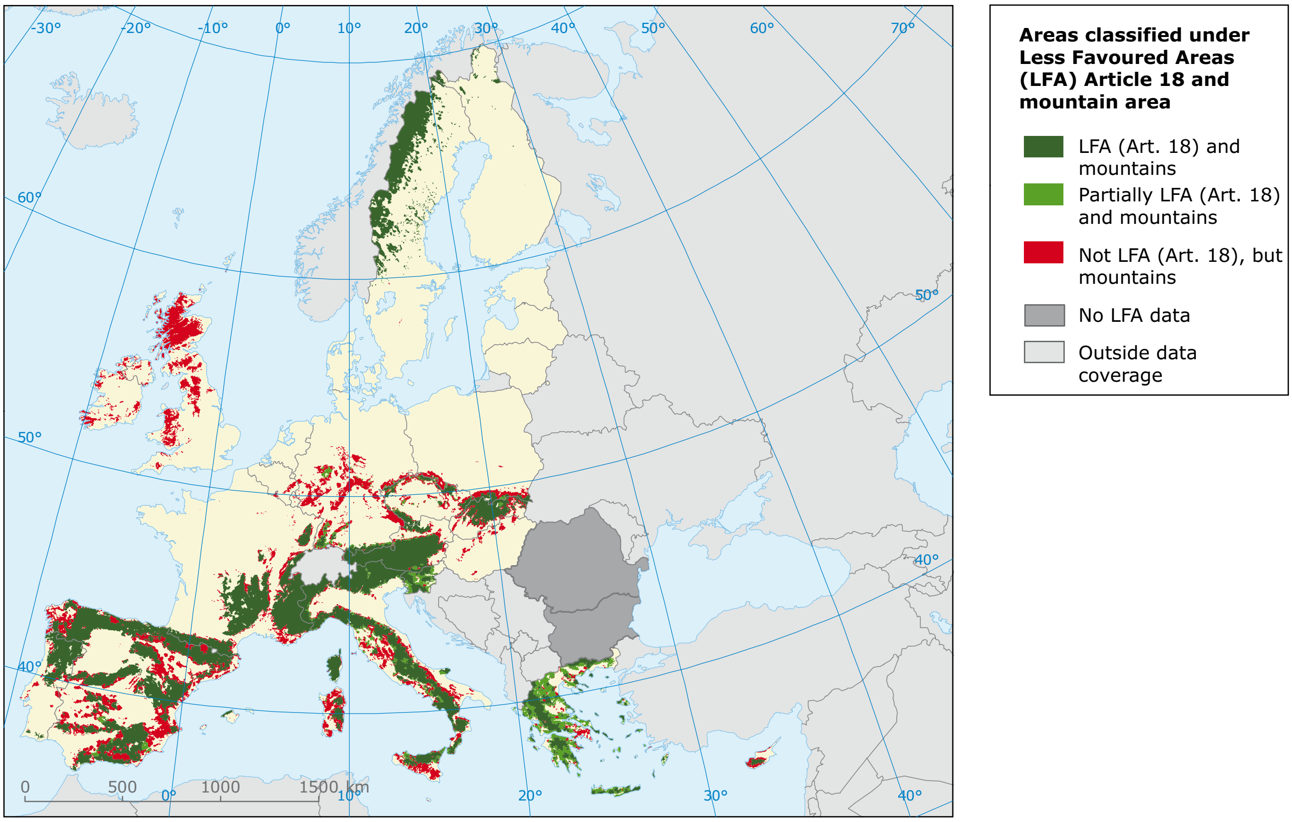
7.4 European designations of land uses in mountain areas

As discussed in Chapter 1, the only policy instrument that has focused specifically on mountain areas at the scale of the European Union has been Article 18 of the LFA regulation. However, mountain land uses also have other particular characteristics recognised under other articles of the Rural Development Regulation (Council Regulation EC No 1257/1999) as well as through the concept of High Nature Value farmland. This section presents the distribution of land defined under in these ways and compares them.

7.4.1 Less Favoured Areas

The Rural Development Regulation (Council Regulation EC No 1257/1999) not only recognises mountain land under Article 18, but also land within three other categories: areas with environmental restrictions (Article 16); areas in danger of abandonment of land use (Article 19); and areas with specific handicaps (Article 20). As shown in Table 7.8 and Map 7.5, 69 % of the mountain area of the EU (excluding Bulgaria and Romania, where Less Favoured Areas (LFAs) have not been defined) is classified under Article 18. There are significant differences between countries. None of the mountainous areas of Hungary, Ireland or the United Kingdom are classified under Article 18. There are also three

Map 7.5 Area classified under LFA Article 18 and mountain area



other countries where a relatively low proportion of their mountain area is classified under Article 18: Germany (25 %), Cyprus (34 %) and Poland (37 %). In Germany, these areas are principally those outside Bavaria and Baden-Württemberg. In Cyprus, it should be noted that the LFA is only in the part of the island that is within the EU, and therefore does not include the mountains in the northeast, which are within the '*Turkish* Republic of Northern *Cyprus'*. In Poland, the primary reason appears to be that only higher-altitude areas are defined under Article 18. Conversely, 42 % of the area classified under this Article is outside the area defined as mountain. A large proportion of this (30 % of the area) is within Sweden and Finland, deriving from the agreement made on accession that areas north of 62 °N would be classified as 'mountain areas' under Article 18. Other countries where a large proportion of the national area classified under Article 18 is outside the mountain area are Czech Republic (31 %), Germany (25 %) and Portugal (25 %).

While only 69 % of the mountain area of the EU (excluding Bulgaria and Romania) is classified under Article 18, a further 23 % of this area is classified under Articles 16, 19 and 20, bringing the overall percentage of the area to 92 % (Table 7.9). As shown in Table 7.9, in terms of area, the lack of mountain land classified under Article 18 LFA in Hungary, Ireland, and the United Kingdom is compensated by classification under the other Articles; thus, 52 % of the mountain area of Hungary, and 98 % of the mountain area of Ireland and the United Kingdom is classified as LFA under Articles 16, 19, or 20. Comparable patterns are found in the other three Member States with a relatively small proportion of their mountain area classified under Article 18; thus 42 % of the mountain area of Cyprus (all of the area within the EU part of Cyprus), 53 % of the mountain area of Poland, and 68 % of the mountain area of Germany is classified as LFA under Articles 16, 19, or 20. It should, however, be noted that very significant areas of all EU Member States — not only in mountain areas — are classified as LFA under one of these four articles (Map 7.6). Conversely, some 74 000 km^2 of mountain area (6 % of the total for Europe) is not included under any of these articles. These mountains are generally at lower elevations, particularly in Spain (34 014 km^2: 12.3 % of mountain area), Italy (13 024 km^2: 7.2 %, especially in Sicily), and France (8 434 km^2: 6.1 %, especially in Provence), as well as Germany (3 888 km^2: 6.7 %, especially in the Harz), Greece (3 229 km^2: 3.4 %, especially in Attiki), the Czech Republic (2 650 km^2: 10.3 %) and Hungary (2 264 km^2: 47.6 %) (Map 7.7).

7.4.2 High Nature Value farmland

The High Nature Value (HNV) farming concept was established in the early 1990s and describes those types of farming activity and farmland that, because of their characteristics, can be expected to support high levels of biodiversity or species and habitats of conservation concern. The EU and its Member States have committed themselves to supporting and maintaining HNV farming, especially through Rural Development Programmes (RDPs) (Beaufoy, 2008; see Section 1.2.3). The HNV approach has also been applied outside the EU; for example, in Turkey (Box 7.6). The dominant characteristic of HNV farming is its low intensity and a significant presence of semi-natural vegetation. A high diversity of land cover (mosaic) under low-intensity farming may enable significant levels of biodiversity to survive, especially if there is a high density of features providing ecological niches. However, a high diversity of such land cover alone does not indicate HNV farming. Typical HNV farmland areas are extensively grazed uplands, Alpine meadows and pasture, steppic areas in eastern and southern Europe, and dehesas and montados in Spain and Portugal. Certain more intensively farmed HNV areas in lowland Western Europe can also host concentrations of species of particular conservation interest, such as migratory waterfowl (IEEP, 2007). Because of these characteristics, there is a widely acknowledged need for measures to prevent the loss of HNV farmland, and therefore, an HNV farmlands dataset has been created to fill the gap in pan-European data on distribution and conservation status of HNV farmland in order to take adequate conservation measures (Paracchini *et al.*, 2008). The dataset used here combines:

- the result of the selection of specific CLC2000 classes in combination with Farm Accountancy Data Network (FADN) data/national datasets;
- the reselection of CLC2000 classes in selected Natura 2000 sites;
- the reselection of CLC2000 classes in selected Important Bird areas;
- the reselection of CLC2000 classes in selected primary butterfly areas.

These layers were upscaled to a resolution of 1 km and combined to create the total HNV dataset with

Table 7.8 National areas (in ha) classified under LFA Article 18 (mountains/hills) in both mountain and non-mountain areas, as defined for this study

Article 18 — mountains and hills	Mountains			No mountains			Sub-total mountains	Sub-total no mountains	LFA	Country area		
Country	P	T	No LFA	P	T	No LFA			P+T		% of mountain area under LFA	% of LFA outside mountains
Austria	1 515	55 162	5 278	391	2 628	18 947	61 955	21 966	59 696	83 921	91 %	5 %
Belgium			1 340			29 321	1 340	29 321		30 662		
Cyprus		1 433	2 827		15	4 975	4 260	4 990	1 448	9 250	34 %	1 %
Czech Republic	2 978	11 939	10 750	2 823	3 802	46 567	25 667	53 192	21 542	78 859	58 %	31 %
Denmark						43 360	-	43 360	-	43 360		
Estonia						45 330	-	45 330	-	45 330		
Finland		5 028	3	1 541	258 137	73 073	5 031	332 751	264 706	337 782	100 %	98 %
France		115 040	22 490		11 815	399 831	137 530	411 646	126 855	549 176	84 %	9 %
Germany	6 786	7 676	43 299	4 071	702	295 133	57 761	299 906	19 235	357 667	25 %	25 %
Greece	44 848	41 582	8 451	16 571	2 677	17 885	94 881	37 133	105 678	132 014	91 %	18 %
Hungary			4 754			88 262	4 754	88 262		93 018		
Ireland			10 096			60 083	10 096	60 083		70 179		
Italy	14 594	117 442	49 167	10 163	2 765	107 357	181 203	120 285	144 964	301 488	73 %	9 %
Latvia						64 602	-	64 602	-	64 602		
Lithuania						64 891	-	64 891	-	64 891		
Luxembourg			212			2 384	212	2 384	-	2 596		
Malta			35			281	35	281	-	316		
Netherlands						37 356	-	37 356	-	37 356		
Poland	757	5 236	10 314	2	333	295 248	16 307	295 583	6 328	311 890	37 %	5 %
Portugal		28 437	6 543	38	9 676	47 495	34 980	57 209	38 151	92 189	81 %	25 %
Slovakia	361	21 219	7 877		624	18 948	29 457	19 572	22 204	49 029	73 %	3 %
Slovenia	6 214	8 957	206	3 024	309	1 560	15 377	4 893	18 504	20 270	99 %	18 %
Spain	3 407	174 377	96 830	724	22 188	208 437	274 614	231 349	200 696	505 963	65 %	11 %
Sweden	205	91 956	114	12 033	199 154	145 981	92 275	357 168	303 348	449 443	100 %	70 %
United Kingdom			60 952			184 559	60 952	184 559	-	245 511	0 %	
Europe	81 665	685 484	341 538	51 381	514 825	2 301 866	1 108 687	2 868 072	1 333 355	3 976 762	69 %	42 %
Europe *	81 460	588 500	280 469	37 807	57 534	1 898 253	950 429	1 993 594	765 301	2 944 026	70 %	12 %

Note: P: partial community is eligible for LFA funding; T: total community is eligible for LFA funding; No LFA: communities are not eligible for LFA funding. * = excl. the United Kingdom, Sweden and Finland.

Source: LFA: EUROSTAT GISCO download service. However the data represents the LFA 2001–2006, excluding Romania and Bulgaria. Download: http://epp.eurostat.ec.europa.eu/portal/page/portal/gisco/geodata/reference file: LFA_03M_2001_SH.zip [accessed July 2010].

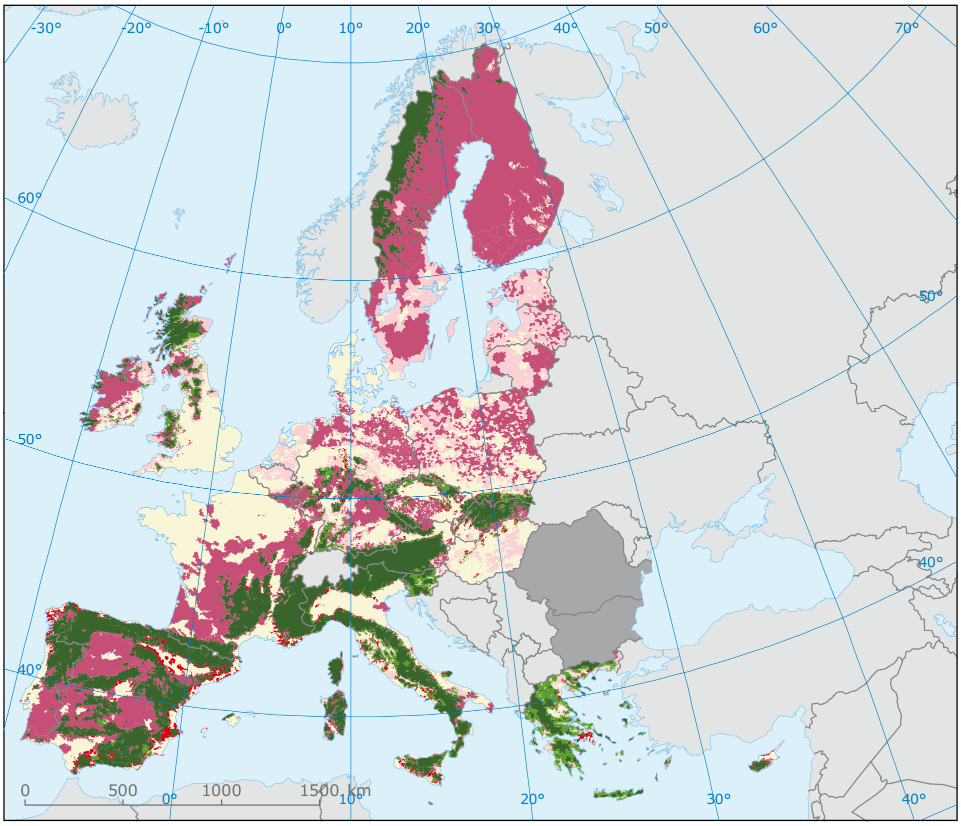
Table 7.9 National areas (in ha) classified under LFA Article 16, 18, 19. 20 in both mountain and non-mountain areas, as defined for this study

All LFA articles (16, 18, 19, 20)	Mountains			No mountains					LFA	Country area		
Country	P	T	No LFA	P	T	No LFA	Sub-total mountains	Sub-total no mountains	P+T		% of mountain area under LFA	% of LFA outside mountains
Austria	2 442	58 599	914	2 522	7 508	11 936	61 955	21 966	71 071	83 921	99 %	14 %
Belgium	116	1 224	–	11 730	6 408	11 184	1 340	29 322	19 478	30 662	100 %	93 %
Cyprus		3 246	1 014		1 093	3 897	4 260	4 990	4 339	9 250	76 %	25 %
Czech Republic	4 647	18 370	2 650	6 424	20 140	26 628	25 667	53 192	49 581	78 859	90 %	54 %
Denmark				3 888	373	39 099	–	43 360	4 261	43 360		100 %
Estonia				29 830	12 091	3 409	–	45 330	41 921	45 330		100 %
Finland		5 028	3	2 590	319 671	10 490	5 031	332 751	327 289	337 782	100 %	98 %
France	217	128 879	8 434	789	159 795	251 062	137 530	411 646	289 680	549 176	94 %	55 %
Germany	14 388	39 485	3 888	64 581	130 301	105 024	57 761	299 906	248 755	357 667	93 %	78 %
Greece	47 165	44 487	3 229	23 288	6 348	7 497	94 881	37 133	121 288	132 014	97 %	24 %
Hungary	2 486	4	2 264	28 999	20	59 245	4 754	88 264	31 509	93 018	52 %	92 %
Ireland	1 296	8 645	155	11 540	36 622	11 921	10 096	60 083	58 103	70 179	98 %	83 %
Italy	23 539	144 640	13 024	19 799	19 470	81 016	181 203	120 285	207 448	301 488	93 %	19 %
Latvia				44 762	14 311	5 529	–	64 602	59 073	64 602		100 %
Lithuania				32 609	26 995	5 287	–	64 891	59 604	64 891		100 %
Luxembourg	42	170	–	225	2 105	54	212	2 384	2 542	2 596	100 %	92 %
Malta		35	–		275	6	35	281	310	316	100 %	89 %
Netherlands				19 501	1	17 854	–	37 356	19 502	37 356		100 %
Poland	6 373	8 310	1 624	94 972	111 814	88 797	16 307	295 583	221 469	311 890	90 %	93 %
Portugal		33 599	1 381	38	41 703	15 468	34 980	57 209	75 340	92 189	96 %	55 %
Slovakia	960	28 048	449	2 734	9 352	7 486	29 457	19 572	41 094	49 029	98 %	29 %
Slovenia	6 214	9 106	57	3 529	643	721	15 377	4 893	19 492	20 270	100 %	21 %
Spain	3 407	237 193	34 014	724	155 381	75 244	274 614	231 349	396 705	505 963	88 %	39 %
Sweden	291	91 974	10	74 143	263 361	19 664	92 275	357 168	429 769	449 443	100 %	79 %
United Kingdom	14 902	44 996	1 054	44 819	34 355	105 385	60 952	184 559	139 072	245 511	98 %	57 %
Europe	128 485	906 038	74 164	524 036	1 380 136	963 903	1 108 687	2 868 075	2 938 695	3 976 762	93 %	65 %
Europe *	113 075	640 189	64 666	404 285	922 625	587 792	817 930	1 914 702	2 080 174	2 732 632	92 %	64 %

Note: P: partial community is eligible for LFA funding; T: total community is eligible for LFA funding; No LFA: communities are not eligible for LFA funding. * = excl. the United Kingdom, Sweden and Finland.

Source: LFA: EUROSTAT GISCO download service. However the data represents the LFA 2001–2006, excluding Romania and Bulgaria. Download: http://epp.eurostat.ec.europa.eu/portal/page/portal/gisco/geodata/reference file: LFA_03M_2001_SH.zip [accessed July 2010].

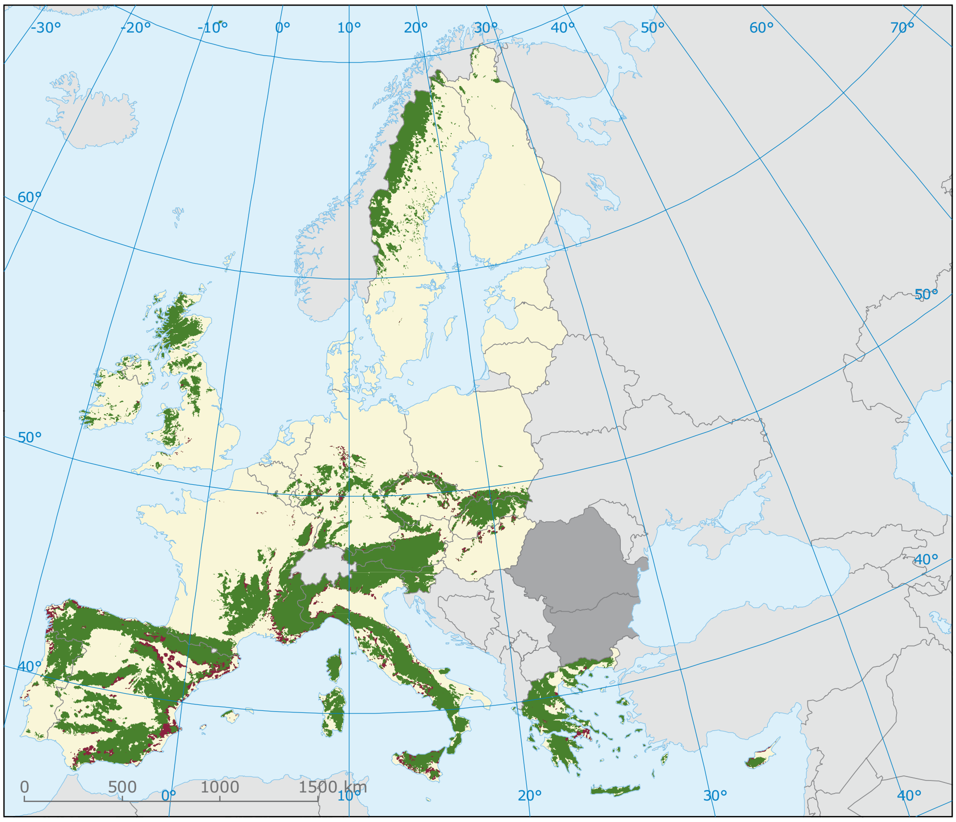
Map 7.6 Area classified under LFA Articles 16, 18, 19 and 20 and mountain area



Areas classified under Less Favoured Areas (LFA) Articles 16, 18, 19 or 20 and mountain area

- LFA and mountains
- Partially LFA and mountains
- Not LFA, but mountains
- LFA, but not mountains
- Partially LFA, but not mountains
- No LFA data
- Outside data coverage

Map 7.7 Mountain areas not classified under LFA Articles 16, 18, 19 or 20



Mountain areas not classified under Less Favoured Areas (LFA) Articles 16, 18, 19 or 20

- Not LFA (16, 18, 19, 20), but mountains
- LFA and mountains
- No LFA data
- Outside data coverage

Box 7.6 Identifying HNV farmland types in Turkey

Turkey's rich biodiversity has been vital in the development of agriculture, horticulture and animal husbandry over more than 10 000 years (Lise and Stolton, 2010). Approximately half (53 %) of country's area is used for crop and livestock production. While the share of agriculture in total GDP has been declining each year (for example, from 26.1 % in 1980 to 9.2 % in 2006), almost a third of the Turkish population are involved in agriculture. The High Nature Value (HNV) farming concept is highly relevant due to the long history of traditional agriculture. This results in many important semi-natural habitats and large areas of low intensity agriculture, which provide key habitats for wildlife.

Following the typology developed by the EEA and UNEP (2004), a typology of HNV farming systems in Turkey was developed within the 'Supporting the Development of a National Agri-environment Programme for Turkey' project, implemented in 2006–2008 by the Bugday Association for Supporting Ecological Living and the Avalon Foundation (Redman and Hemmami, 2008). The main types are:

- extensive crop production (predominantly HNV Type 2 farmland — mix of semi-natural vegetation and low intensity cropland) with crop rotations using mainly local cultivars of cereals, pulses and forage crops in dry land areas combined with extensive livestock grazing;
- extensive livestock production (predominantly HNV Type 1 farmland — 100 % semi-natural) with highland mixed farming systems (rangeland grazing with meadows and forage crops used for hay, and some cropping); and with alpine farming systems (grazing on alpine pastures with meadows for hay), with some traditional mountain pastoralism;
- extensive forest farming (predominantly HNV Type 1 and Type 2 farmland) with mixed farming systems (rangeland grazing with meadows and forage crops used for hay, and some cropping) (see photo below); extensive livestock grazing with no cropping; and traditional mountain pastoralism.

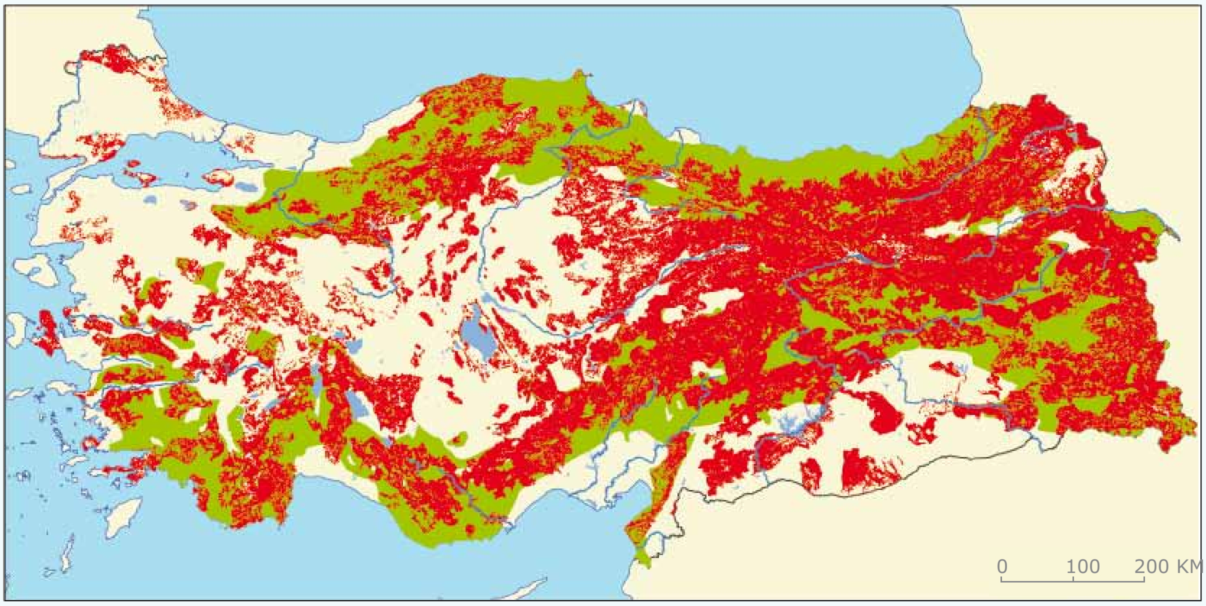
An HNV map of Turkey was developed through three stages of mapping: 1) land use and current agricultural practices; 2) Mapping of key biodiversity areas and biodiversity values from the national database for vascular plants, birds, mammals, amphibians, reptiles, butterflies, freshwater fish and dragonflies; 3) local breeds of cattle, sheep and goats. The map was finalised using CLC data, and shows that 25.9 million ha of Turkey (33.3 % of the total area) is classified as HNV farmland, of which 66.7 % (17.2 million ha) is in the mountains (Map 7.8). These areas require specific natural resource and agriculture management systems and new incentive schemes.

Source: Yildiray Lise (United Nations Development Programme Turkey Office); Melike Hemmami, Murat Ataol and Doğa Derneği (Nature Association, Turkey).

Photo: © Yildiray Lise
Extensive mixed farming systems, associated with villages in the lowland areas, dominated by livestock (cattle and sheep) in Küre Mountains National Park, Turkey.

Box 7.6 Identifying HNV farmland types in Turkey (cont.)

Map 7.8 High Nature Value farmland in the mountains of Turkey, defined as areas above 750 m



High Nature Value (HNV) farmland in the mountains of Turkey, defined as areas above 750 m

Mountains

HNV farmland

the rule that the maximum value of the four is retained.

HNV farmland covers approximately 17 % of the area of the EU-27 as a whole. However, in the mountains of these Member States — excluding the Nordic mountains, where there is very little arable or pasture land in the mountains of Finland and Sweden (Figure 7.2) — the proportion is almost double: 32.8 %. Table 7.10 shows the distribution at the massif level. The greatest area of HNV farmland in mountains is in the Iberian mountains, and the second greatest area is in the mountains of the Balkans/South-east Europe; in both of these massifs, the proportion is just slightly less than 40 %. Other massifs with particularly high proportions are the mountains of the British Isles (56.8 %: Box 7.7), the eastern and western Mediterranean islands (54.9 %, 53.6 %), the French/Swiss middle mountains (35.4 %), and the Pyrenees (30.0 %). Apart from the Nordic mountains, the lowest proportions are found in the central European middle mountains 1 and 2. One explanation may be that these are lower mountains, which are largely forested and have been more intensively managed; this conclusion merits further investigation.

7.4.3 *Overlap of LFA and HNV farmland in mountain areas*

As noted in Chapter 1, a major challenge for the development and implementation of policies for Europe's mountain areas relates to the overlap between designations that were, at least originally, developed with different aims. The two types of designations presented in this section are a case in point: LFAs have a history dating back to the mid-1970s for the purposes of supporting agricultural production, while the concept of HNV farmland emerged in the early 1990s and, while addressing particular modes of agricultural production, has a strong emphasis on management

Box 7.7 HNV farmland in the mountains of England

Mountain areas in England support extensive livestock production, with sheep moving seasonally between agriculturally improved, semi-improved and higher altitude unimproved land, and beef cattle staying on the lower slopes or around the farm. Historically, cattle were more prevalent, but were replaced gradually by sheep as wool became more profitable (Dark, 2004; Williamson, 2002) and, more recently, due particularly to changes in agricultural subsidies (Winter *et al.*, 1998). Generations of farmers have adapted to and manipulated this environment, leading to over 70 recognised vegetation communities (Backshall *et al.*, 2001), which are synonymous with this High Nature Value (HNV) landscape supported by other land management such as sporting estates.

A typical upland farm has three distinctive land types, each with specific habitats (Figure 7.13). In the valley bottom lie the inbye fields demarcated with dry stone walls and formerly cut in late summer to provide winter fodder. With the advent of silage production, many of these hay meadows have disappeared; they are now one of the rarest semi-natural habitats (JNCC, 2007). Whilst silage is nutritionally far more beneficial for livestock, the grassland is impoverished through increased soil nutrient status, drainage and re-seeding; as a result, populations of passerines and waders in the Pennines have declined sharply (Fuller *et al.*, 2002). Further up the valley sides are the semi-improved intakes**,** supporting a range of wet grassland and flush communities, and used by farmers for grazing in winter or when stock need to be closer to the farm (for example, at lambing time). Increasing economic pressure on farm businesses has led to many intakes being improved, losing their ecological richness.

Open fell covers the highest land. These extensive areas are in sole ownership but, historically, each farmer had grazing rights in a system of communal land management (Aitchison and Gadsden, 1992). Over time, the sheep have developed an inherent behavioural ability to stay on specific grazing areas without active shepherding. This instinct is passed from mother to lambs as long as an intergenerational flock is maintained, gathered from time to time for animal welfare or sale. A particularly widespread habitat is heather moorland; a mosaic of grassland, dwarf shrub heath (DSH) and bogs, with some internationally rare communities, such as *Calluna vulgaris — Ulex gallii* dry heath, designated as SACs. For agriculture, these habitats provide little grazing, so stocking densities are kept low. These low rates and related sporting estate management have perpetuated heather moorland until quite recently. The introduction of headage payments nationally (1947 to 1974) and the subsequent LFA Directive (1975 to 2001) encouraged many farmers to overstock and overgraze, impoverishing ecological diversity, replacing DSH with less ecologically desirable communities, or triggering extensive soil erosion (Bardgett *et al.*, 1995).

Policy change towards agri-environment grants and then Agenda 2000 modulation away from production has encouraged the de-stocking of many farms. Coupled with dwindling labour, lower stocking has become problematic as sheep spread further, requiring complex and costly gathering. Lower rates have also led to undergrazing and the spread of less palatable coarse grasses and *Pteridium aquilinium*, lowering ecological interest. To maintain and enhance these unique HNV upland farmlands requires that financial reward goes beyond the current system of profit-foregone, including recognition of the ecosystem services provided.

Source: Lois Mansfield (University of Cumbria, the United Kingdom).

Figure 7.13 High Nature Value farming landscape in the mountains of northern England

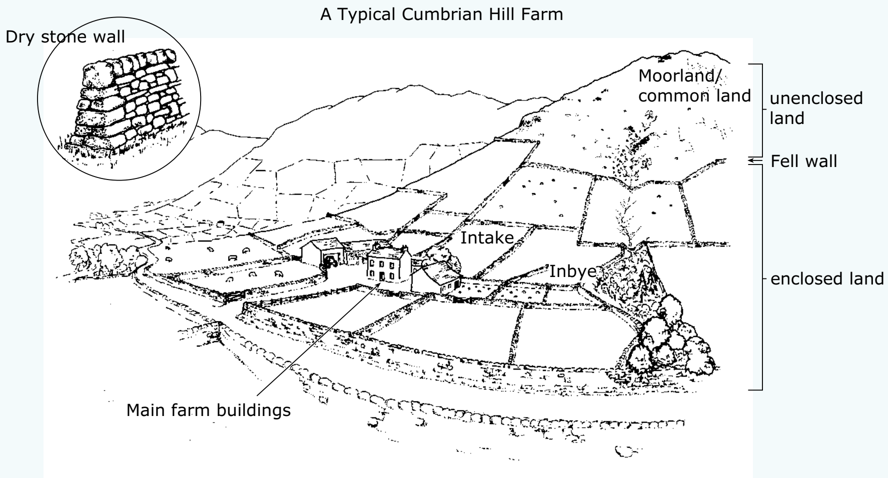


Table 7.10 Total area and proportion of massif areas covered by HNV farmland, indicating countries not included in HNV dataset

	Massif area covered by HNV (km²)	% of massif area covered by HNV	Countries without HNV designation
Alps	41 655	24.9	Switzerland
Apennines	27 556	24.7	
Atlantic islands	–	–	Portuguese and Spanish islands
Balkans/South-east Europe	56 633	38.5	Albania, Bosnia and Herzegovina, Croatia, the former Yugoslav Republic of Macedonia, Montenegro, Serbia
British Isles	40 211	56.8	Faroe Islands
Carpathians	29 631	21.4	Moldova, Ukraine
Central European middle mountains 1 *	4 632	12.2	
Central European middle mountains 2 **	9 444	20.8	
Eastern Mediterranean islands	9 531	54.9	
French/Swiss middle mountains	24 656	35.4	Switzerland
Iberian mountains	102 382	39.0	
Nordic mountains	363	0.4	Iceland, Norway
Pyrenees	16 379	30.0	Andorra
Western Mediterranean islands	12 885	53.6	
Total (without Nordic countries)	375 596	32.8	

Note: * = Belgium and Germany; ** = the Czech Republic, Austria and Germany.

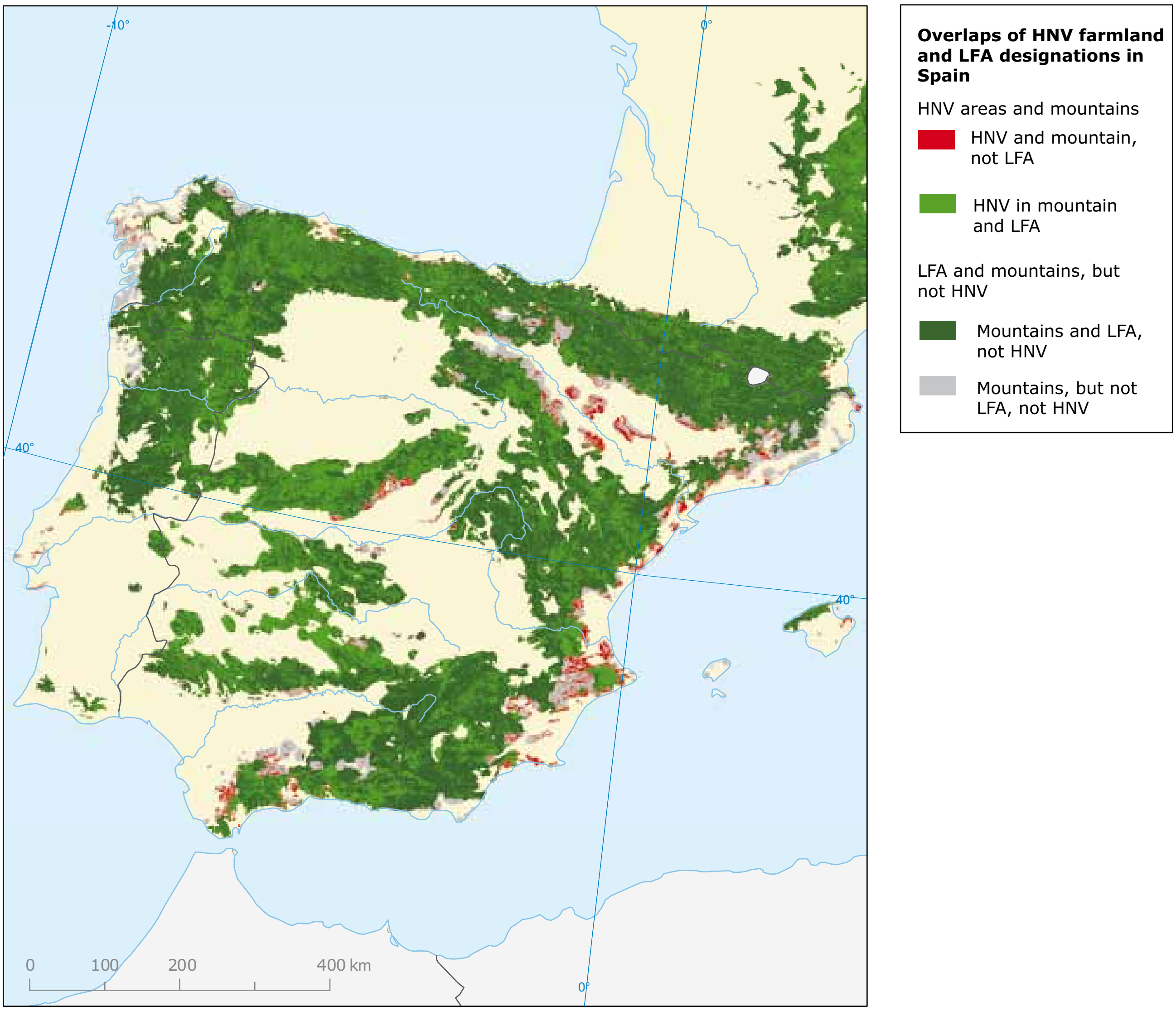
Source: Based on JRC datasets (HNV).

Table 7.11 Overlaps of HNV and LFA designations in mountain areas

	Within LFA		Outside LFA		Total area	Total HNV area	HNV inside mountains without LFA (%)
Country	**Total area**	**HNV area**	**Total area**	**HNV area**			
Austria	61 033	19 198	911	222	61 944	19 420	1.1
Belgium	1 336	301	1	0	1 337	302	0.0
Cyprus	3 242	1 402	1 010	472	4 252	1 873	25.2
Czech Republic	22 983	4 961	2 638	196	25 622	5 156	3.8
Finland	5 010	17	3	0	5 013	17	1.0
France	128 988	44 367	8 399	1 488	137 387	45 854	3.2
Germany	53 736	7 159	3 867	150	57 603	7 309	2.1
Greece	91 531	44 674	3 218	1 148	94 749	45 822	2.5
Hungary	2 480	363	2 255	270	4 735	633	42.6
Ireland	9 865	5 599	154	38	10 019	5 638	0.7
Italy	168 019	45 701	12 967	2 797	180 986	48 498	5.8
Luxembourg	209	10	0	0	209	10	0.0
Malta	34	9	0	0	34	9	0.0
Poland	14 673	2 596	1 621	265	16 294	2 861	9.3
Portugal	30 816	9 881	1 328	263	32 144	10 145	2.6
Slovakia	28 974	4 138	446	25	29 419	4,163	0.6
Slovenia	15 306	3 968	58	19	15 364	3 988	0.5
Spain	235 759	93 080	33 157	10 518	268 916	103 599	10.2
Sweden	92 058	218	9	0	92 067	218	0.0
United Kingdom	59 705	34 352	1 047	166	60 751	34 518	0.5
Total	**1 025 757**	**321 995**	**140 407**	**18 038**	**1 166 165**	**340 033**	**5.3**

Sources: LFA: EUROSTAT GISCO download service. However the data represents the LFA 2001–2006, excluding Romania and Bulgaria. Download: http://epp.eurostat.ec.europa.eu/portal/page/portal/gisco/geodata/reference file: LFA_03M_2001_SH.zip [accessed July 2010]. HNV: EEA-JRC Project on High Nature Value farmland, 100 x 100 m HNV data, delivery May 2008. Paracchini *et al.*, 2008.

Map 7.9 Overlaps of HNV farmland and LFA designations in Spain



for the conservation of biodiversity. As shown in Table 7.11, across the mountain areas of the EU-27, there is a very large overlap between HNV and LFA (Articles 16, 18, 19, 20) and HNV: only just over 5 % of the area of HNV farmland within mountains is not covered by any LFA scheme. In one country, Hungary, nearly half of the HNV in its mountain area is not within an LFA designation. However, this is also a country with a small mountain area, and the lowest proportion of its mountain area under LFA designation. In Cyprus, another country with a relatively small mountain area, just over a quarter of the mountain area is neither HNV farmland nor under LFA designation; a large part of this is in northern Cyprus. Of countries with a significant mountain area, 10.2 % of Spain is HNV farmland but not designated as LFA; most of this is at lower altitudes, as can be seen from a comparison between Maps 7.7 and 7.9. A similar situation may be found in Poland (9.3 %) and Italy (5.8 %).

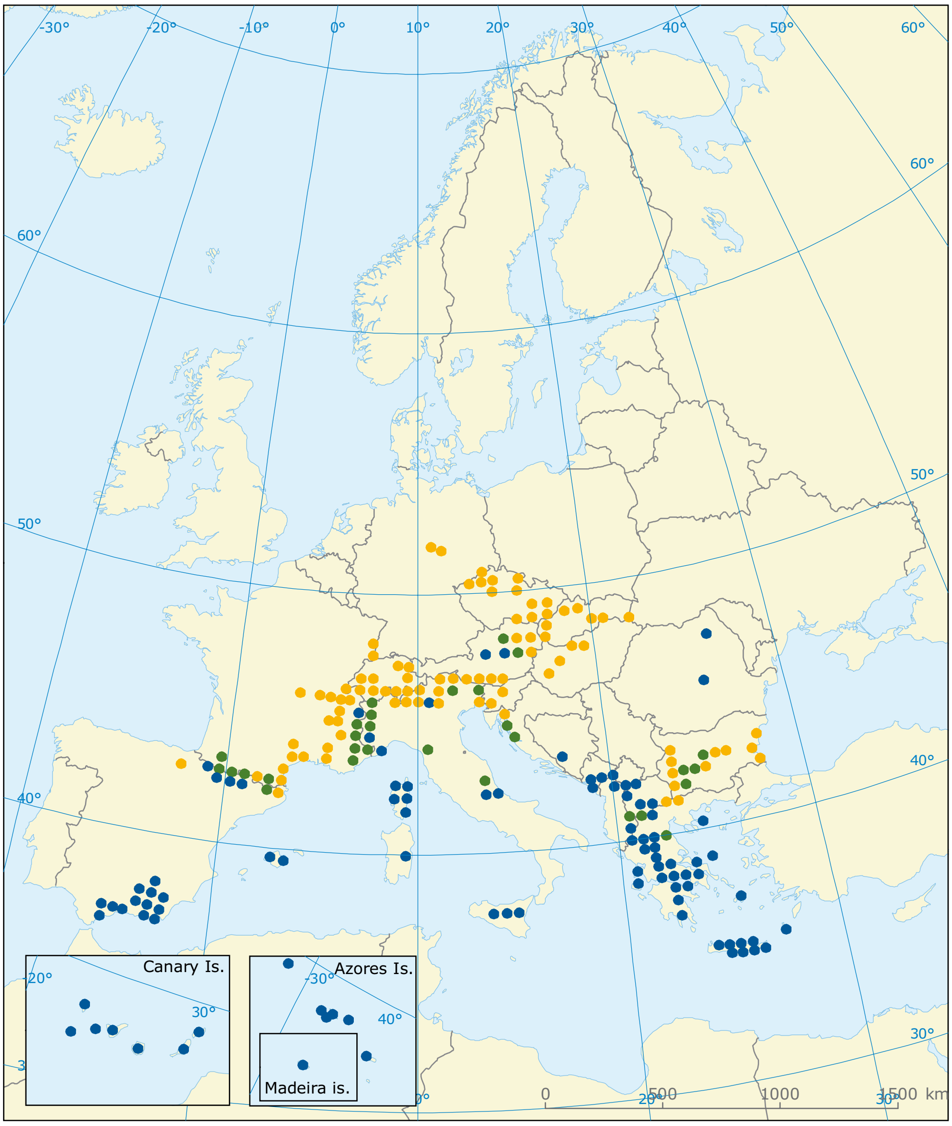
8 Biodiversity

At the global scale, mountains are centres of biodiversity. For instance, of the 25 global hotspots identified by Conservation International (Mittermeier *et al.*, 2005), all but two are entirely or partly mountainous. Two of these hotspots — the Mediterranean Basin and the Irano-Anatolian — include mountains in southern and south-eastern Europe. Similarly, within Europe, most hotspots of plant, bird and mammal diversity are in mountain areas (Map 8.1). A number of factors interact to cause these high levels of biodiversity (Körner, 2002). These include the compression of thermal and climatic zones over relatively short distances, steep slopes, the diversity of aspects, variations in geology and soils, and the fragmentation of mountain terrain. In addition, many mountain areas are isolated from one another either in terms of distance or because of unsuitable habitats — at least since the end of the last Ice Age, or because of significant anthropogenic modification of lowland ecosystems — so that species have evolved separately; a major reason for the high levels of endemism in many mountains. Species endemism often increases with altitude (Nagy and Grabherr, 2009; Schmitt, 2009). Within mountain areas themselves, centuries or millennia of human intervention, particularly through burning and grazing, have also been important for maintaining populations of many species and particular habitats in spatially diverse cultural landscapes.

In the mountains of Europe, while some publications have considered all mountain ecosystems (for example, Ozenda, 2000), a major focus of research attention has been on the biodiversity of the alpine life zone, i.e. land above the tree line, which covers about 3 % of the continent's area, ranging from approximately1 % of the area of the mountains of Corsica to 40 % of the area of the Italian Alps (Nagy *et al.*, 2003b). Although limited in its extent, and often including significant proportions of unvegetated rock, snow and ice, this life zone includes about 20 % of Europe's plant species (Väre *et al.*, 2003),with numbers of vascular plants decreasing from south to north and numbers of cryptogams (bryophytes and macrolichens) showing the opposite trend (Virtanen *et al.*, 2003). The diversity of the alpine life zone is further increased by its fauna (Nagy *et al.*, 2003a). For this life zone, our knowledge of the distribution of certain vertebrates, especially certain groups of birds, is quite good, though basic questions such as the variable(s) that govern presence or absence often remain unanswered (Thompson, 2003); overall knowledge of invertebrates is patchy, though groups such as the Lepidoptera, Coleoptera and Arenaea are better documented (Brandmayr *et al.*, 2003). Nevertheless, while the alpine life zone includes a significant proportion of the total biodiversity of Europe's mountain areas, it is smaller than the alpine biogeographic zone described in Section 1.3.6; and the number of both plant and animal species decreases with altitude (Körner, 2002; Nagy and Grabherr, 2009). Thus, overall, the wide range of mountain habitats — alpine, forested, grazed, mown, burned, cultivated, and wet — includes a significantly larger number of species.

Within the European Union, the primary policy instruments aimed at the conservation of biodiversity are the Birds Directive (European Commission, 1979) and Habitats Directive (EC, 1992) (see Chapter 1). Birds are considered in Section 8.2; the following section is drawn mainly from reports under Article 17 of the Habitats Directive, which requires Member States to report on its implementation every six years. The most recent reporting period covers the period 2001–2006 (EC, 2009); consequently, reports for this period are a primary source for this chapter. However, this means that much of the available analysis is restricted to the mountains of EU Member States — with the exception of Bulgaria and Romania, as they only joined the EU in 2007 — and that Switzerland, Norway, Iceland and the countries in the Balkans that are not Member States of the EU are not considered. Apart from this work, the most comprehensive source of information on biodiversity in mountain areas — though almost entirely in the alpine life zone — is Nagy *et al.* (2003), which resulted from the Alpine Biodiversity Network (ALPNET), sponsored by the European Science Foundation.

Map 8.1 Hotspots of plant, bird and mammal diversity based on species richness and narrow endemism



Hotspots of plant, bird and mammal diversity based on species richness and narrow endemism

- Richness
- Richness and narrow endemism
- Narrow endemism

Source: Williams *et al.*, 1998, updated according to Médail and Quézel, 1999.

8.1 Mountain species and habitats linked to the EU Habitats Directive

The EU Habitats Directive has a number of Annexes. For the purpose of this report, three are of particular relevance. Annex I lists 'natural habitat types of Community interest' that '(i) are in danger of disappearance in their natural range; or (ii) have a small natural range following their regression or by reason of their intrinsically restricted area; or (iii) present outstanding examples of typical characteristics of one or more of the nine following biogeographical regions: Alpine, Atlantic, Black Sea, Boreal, Continental, Macaronesian, Mediterranean, Pannonian and Steppic' (Sundseth and Creed, 2008).

The directive also identifies 'Species of Community interest', which may be designated as endangered, vulnerable, rare or 'endemic and requiring particular attention by reason of the specific nature of their habitat and/or the potential impact of their exploitation on their habitat and/or the potential impact of their exploitation on their conservation status' (EC, 1992). These species are listed in Annex II (for those requiring designation of special areas of conservation), Annex IV (for species in need of strict protection), and Annex V (with regard to species taken from the wild). This section presents an analysis of the mountain habitats and species listed in Annexes I, II and IV of the Habitats Directive.

The geographic scope of the analysis is the mainland of Europe, islands geographically belonging to Europe (including Svalbard, Iceland, Azores, Canary Islands, Madeira and the islands in the Mediterranean Sea, including Cyprus). In general, an altitudinal threshold of 800–1 000 m was used to identify mountain species in temperate and southern Europe; though in the north, especially in the boreal zone, the limit is significantly lower. Consequently, lower areas within the mountain massifs generally used for analysis in this report are not included. In addition, it should be noted that these massifs are not used as a unit of analysis; rather, the biogeographical zones described in Section 1.3.6 are used for certain parts of the analysis.

For species, four categories of species linked to mountain ecosystems were assigned:

- mountain species: species exclusively or almost exclusively linked to mountains;
- predominantly mountain species ('mainly mountain'): species distributed in mountains, but living in lower altitudes as well;
- predominantly not mountain ('facultatively mountain'): species distributed mainly outside mountains, but occasionally occurred in mountains as well;
- non-mountain species: species not occurring in mountains.

For habitat types, three categories were assigned:

- mountain habitats: exclusively or almost exclusively distributed in mountains;
- partially mountain habitats: habitat types distributed both inside and outside mountains;
- non-mountain habitats: habitat types distributed exclusively or almost exclusively outside mountains.

The distribution maps and reports delivered by EU-25 Member States with Article 17 reports in 2007 (Eionet, 2007) were key sources of information for this analysis. These were complemented by published literature, which represented the main source of information about species, habitats and distribution; the most important publications are included in the references. As Internet sources also contributed to decisions regarding the classification of individual species, the main websites used are also listed in the references. For certain species and habitats, information was not sufficient to classify them with full certainty; these were classified with more coarse information. The assignment of individual species of the Habitat Directive Annex II and Annex IV to the above-mentioned categories (first 3 categories, non-mountain species not included) is in Appendix 1, habitat types in Appendix II. Nomenclature is according to the Annexes of the Habitat Directive.

8.1.1 *Distribution of species*

The analysis includes all of the 1 148 taxi listed in Annex II and Annex IV of the Habitats Directive (version 1.1.2007) and covered five taxonomic groups of animals (invertebrates, amphibians, reptiles, freshwater lampreys and fish, and mammals) and three taxonomic groups of plants (mosses and liverworts, ferns, and flowering plants). The classification of individual taxa is in Appendix 1. Table 8.1 presents a statistical summary of results for individual taxonomical groups of organisms, in terms of the numbers of the Habitat Directive organisms classified in the three categories of mountain species mentioned above. The taxonomical group with the highest number of exclusively mountain species was flowering plants; this group is also the most abundant in the Annexes of the Habitats Directive.

Table 8.1 Number of species of different taxonomical groups classified in three categories of mountain species

	Invertebrates	Fish	Amphibians	Reptiles	Mammals	Mosses and liverworts	Ferns	Flowering plants	Total
Mountain species	15	9	5	4	8	6		134	181
Mainly mountain	8	2	14	6	9	11	3	77	130
Facultatively mountain	0	0	0	1	1	2	3	31	38

Considering the high rates of endemism in mountain species, a further stage of analysis was a review of endemism of the 'mountain species' of the Habitat Directive in relation to countries, biogeographical regions used by the Habitat Directive, mountain ranges, islands and some regions of Europe. This review contains all of the three above-mentioned groups of mountain species. Table 8.2 shows the mountain species with a distribution limited to the territory of one country. The highest number of species — of which most are flowering plants — is in Spain; Portugal, Italy and Greece also have quite high numbers.

Table 8.3 shows the number of mountain species in individual taxonomical groups that are restricted by their distribution to a particular biogeographic region. There are 214 of these species: 114 of them endemic to the Mediterranean, 51 to the Macaronesian, and 42 to the Alpine biogeographic region.

Table 8.4 summarises the endemism of mountain species in individual mountain areas, some of which coincide reasonably well with the massifs used elsewhere in the report, while others represent sub-sets of these (for example, the Bohemian range is within central European middle mountains 2; the Dinaric mountains are part of the Balkans/South-east Europe). With regard to the island mountains, the Azores, Madeira and Canary Islands are in the Atlantic islands; the Balearic Islands, Corsica and Sardinia are in the western Mediterranean; Sicily is included with the Apennines; Crete with the Aegean islands and Cyprus with the eastern Mediterranean islands. The Iberian mountains have the greatest level of endemism; as noted above, Spain is the country with the most endemic species — levels in the Canary Islands are also high — and similarly, the majority of endemic species in Portugal are on Madeira and the Azores. The mountains of the Balkans/South-east Europe also have high levels of endemism, followed by the Alps and Carpathians.

Table 8.2 Number of mountain species endemic to one country

Country	Invertebrates	Fish	Amphibians	Reptiles	Mammals	Mosses and liverworts	Ferns	Flowering plants	Total
Austria								1	1
Cyprus								13	13
Czech Republic								2	2
France			2				1	2	5
Greece				1				20	21
Italy	1	1	7					17	26
Portugal	1						1	28	30
Romania		1						2	3
Sweden								1	1
Slovakia						1		3	4
Spain	2		1		1			70	74
Total	**4**	**2**	**10**	**1**	**1**	**1**	**2**	**159**	**180**

Table 8.3 Number of mountain species endemic to each biogeographic region

Biogeographic region	Invertebrates	Fish	Amphibians	Reptiles	Mammals	Mosses and liverworts	Ferns	Flowering plants	Total
Alpine	4		1	2	5	2		28	42
Atlantic								2	2
Continental								5	5
Macaronesian	1						1	49	51
Mediterranean	4		10	3	1		1	95	114
Two or more regions	14	11	8	6	12	17	4	63	135
Total	**23**	**11**	**19**	**11**	**18**	**19**	**6**	**242**	**349**

Recognising that not all endemic species are included within Annexes II and IV of the Habitats Directive, these figures can be compared to those of Väre *et al.* (2003), who found the highest number of endemics and narrow-range taxa in the Alps and the Pyrenees, with high numbers also in the Balkan mountains, Crete and the Sierra Nevada, as well as in the Massif Central, Corsica and the central Apennines.

8.1.2 Distribution of habitats

Of the 231 habitat types listed in the Annex I of the Habitat Directive (version 1.1.2007), 42 can be considered as mountain habitats — i.e. habitats exclusively or almost exclusively distributed in mountains. A further 91 habitat types occur in both mountain and non-mountain areas, and 98 are non-mountain habitats. The results are summarised in Table 8.5 and Figure 8.1, and there is a classification of individual habitat types in Appendix 2.

Considering habitats found in mountain areas (i.e. mountain and both mountain and non-mountain), some key points may be drawn from these results. First, almost half (46 %) of these 135 habitat types are forests, which corresponds with the high proportion of this habitat in Europe's mountains. This includes one habitat group that is only found in mountains (temperate mountainous coniferous forests) and another that is predominantly found in mountains (Mediterranean and Macaronesian mountainous coniferous forests). Second, there is only one habitat group — temperate heath and scrub —with most of its habitat types in mountains. Those that are restricted to mountains are the widespread alpine and boreal heaths and sub-arctic *Salix* spp. scrub and others that are more restricted to the mountains of central Europe (*Mugo-Rhododendrum hirsuti*), the Mediterranean mountains (endemic oro-Mediterranean heaths with gorse), and the Rhodope mountains of Bulgaria (*Potentilla fruticosa*

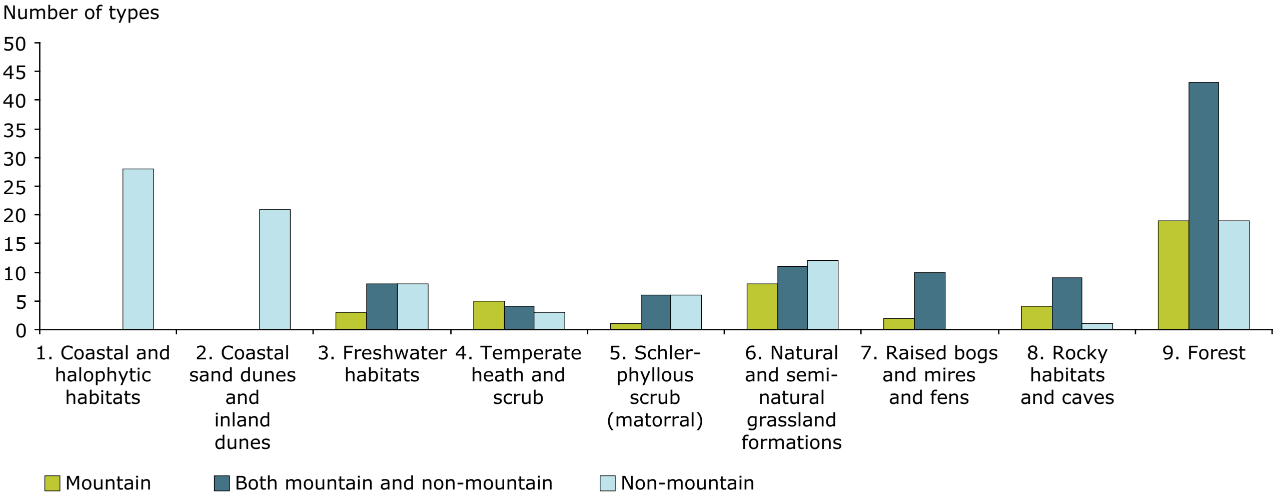
Table 8.4 Number of mountain species endemic to mountain ranges, mountain regions and islands

Area	Invertebrates	Fish	Amphibians	Reptiles	Mammals	Mosses and liverworts	Ferns	Flowering plants	Total
Mountain ranges									
Pyrenees				1	1			5	7
Alps	3		1			1	1	18	24
Apennines			2					3	5
Bohemian range								4	4
Carpathians	1	2			3	1		11	18
Mountain regions									
Iberian	2		2	2	2			56	64
Scandes	1					2		8	11
Dinaric								6	6
Balkan		1	1	1	1			20	24
Island mountains									
Aegean			1					1	2
Azores							1	9	10
Canary Islands								30	30
Balearic			1					3	4
Corsica, Sardinia	2	1	7	1				3	14
Madeira	1							11	12
Sicily							1	2	3
Crete								5	5
Cyprus								13	13
Total	**10**	**4**	**15**	**5**	**7**	**4**	**3**	**208**	**256**

Table 8.5 Number of mountain habitat types in individual habitat groups: 'Both' represents habitats occurring in both mountain and non-mountain areas

Habitat type	Mountain	Both	Non-mountain
1. Coastal and halophytic habitats	0	0	28
11. Open sea and tidal areas			8
12. Sea cliffs and shingle or stony beaches			5
13. Atlantic and continental salt marshes and salt meadows			4
14. Mediterranean and thermo-Atlantic salt marshes and salt meadows			3
15. Salt and gypsum inland steppes			3
16. Boreal Baltic archipelago, coastal and landupheaval areas			5
2. Coastal sand dunes and inland dunes	0	0	21
21. Sea dunes of the Atlantic, North Sea and Baltic coasts			10
22. Sea dunes of the Mediterranean coast			7
23. Inland dunes, old and decalcified			4
3. Freshwater habitats	3	8	8
31. Standing water		5	5
32. Running water	3	3	3
4. Temperate heath and scrub	5	4	3
5. Sclerophyllous scrub (matorral)	1	6	6
51. Sub-Mediterranean and temperate scrub	1	2	1
52. Mediterranean arborescent matorral		2	1
53. Thermo-Mediterranean and pre-steppe brush		1	2
54. Phrygana		1	2
6. Natural and semi-natural grassland formations	8	11	12
61. Natural grasslands	5	3	1
62. Semi-natural dry grasslands and scrubland facies	1	4	7
63. Sclerophillous grazed forests (dehesas)			1
64. Semi-natural tall-herb humid meadows	1	4	1
65. Mesophile grasslands	1		2
7. Raised bogs and mires and fens	2	10	0
71. Sphagnum acid bogs		6	
72. Calcareous fens	1	3	
73. Boreal mires	1	1	
8. Rocky habitats and caves	4	9	1
81. Scree	3	3	
82. Rocky slopes with chasmophytic vegetation		4	
83. Other rocky habitats	1	2	1
9. Forests	19	43	19
90. Forests of boreal Europe	1	6	1
91. Forests of temperate Europe	5	20	12
92. Mediterranean deciduous forests	3	8	2
93. Mediterranean sclerophyllous forests		6	4
94. Temperate mountainous coniferous forests	3		
95. Mediterranean and Macaronesian mountainous coniferous forests	7	3	
Total	**42**	**91**	**98**

Figure 8.1 Number of mountain habitat types in individual groups of habitats



thickets). Third, at the level of habitat types, in addition to the two forest habitat types mentioned above and screes, the majority of natural grassland habitat types are found only in mountains. Two of these are widespread (alpine and sub-alpine calcareous grasslands; siliceous alpine and boreal grasslands) and others are more restricted: siliceous Pyrenean *Festuca eskia* grasslands; Oro-Iberian *Festuca indigesta* grasslands (Iberian mountains); and Macaronesian mesophile grasslands.

8.1.3 Status of habitats

As part of the reporting process under Article 17 of the Habitats Directive, Member States have to report on the conservation status of habitats listed in Annex I of the Directive. A common assessment method has been developed for this purpose (EC, 2005). The outcomes of this method are assessments as to whether the status of a habitat is favourable, unfavourable–inadequate, unfavourable–bad, or unknown. It should be noted that, for the EU as a whole, 13 % of habitat assessments were reported by Member States as unknown, particularly for the countries of southern Europe (EC, 2009). The data used for the analysis below are at a resolution of 10 km x 10 km; the value for each grid cell expresses the occurrence of the habitat within that cell. Using these data, the quantification of values for conservation status followed the method of the European Topic Centre on Biological Diversity (2008) to identify habitats, in sequence, as: 'Unfavourable — bad' (U2); 'Favourable' (FV); 'Unknown' (XX); or 'Unfavourable — inadequate (U1).

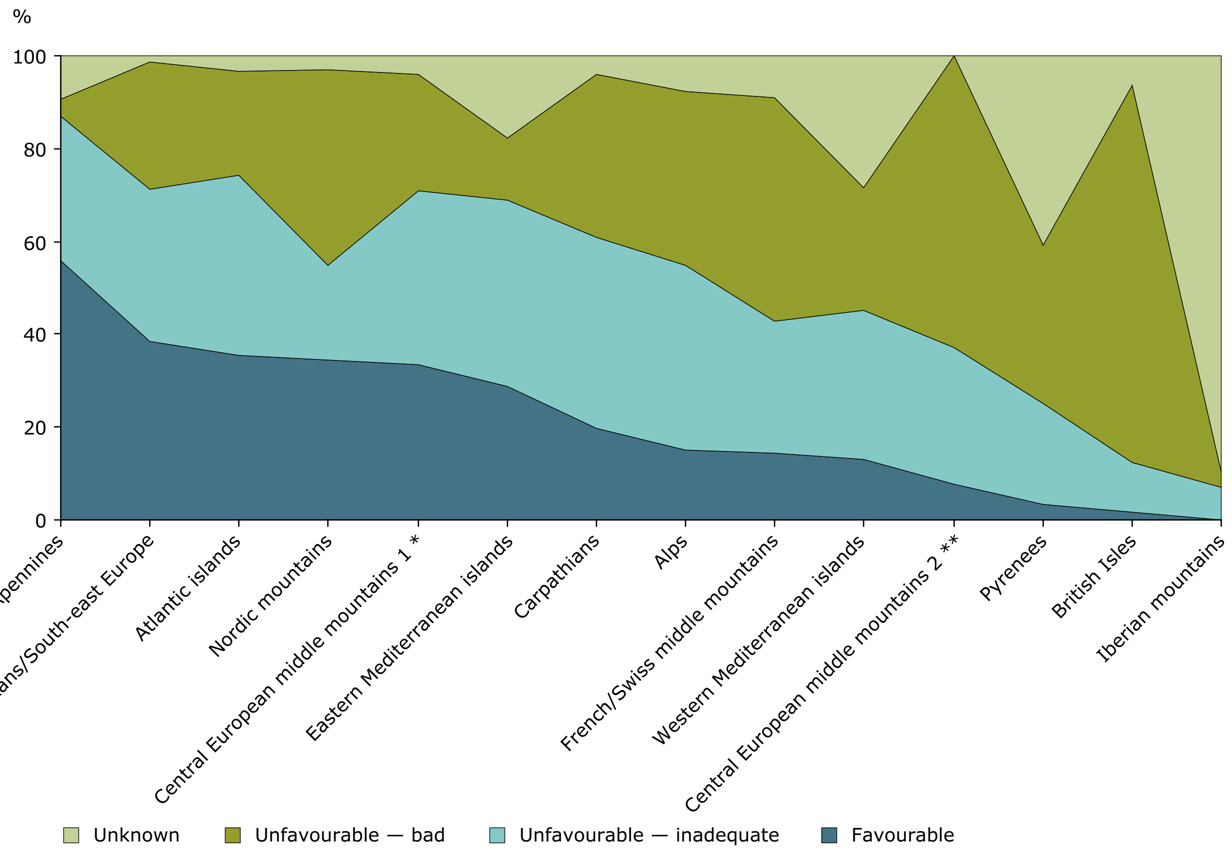
Table 8.6 presents the numbers of habitat types in each massif classified according to these criteria, and Figure 8.2 presents these data as proportions. Overall, 21 % of habitats are assessed as being in favourable status, 28 % are in unfavourable–inadequate status, 32 % are in unfavourable–bad status, and 18 % are unknown. As noted previously, the majority of the latter are in Spain (Iberian mountains, Pyrenees); since the status of 90 % of the habitat types in the Iberian mountains is unknown, this massif is not discussed further here. In Figure 8.2, the massifs are ordered from left to right in terms of the proportion of habitat types in favourable status. Within this category, proportions range from 56 % in the Apennines to almost 0 % in the mountains of the British Isles. There is no clear geographical pattern to these findings. While the proportions of habitat types in favourable status shown in Figure 8.2 may appear low, it should be recognised that one of the criteria for being listed on Annex I was threat or historical decline, so that it would be expected that most habitats and species would to be in an unfavourable status; these results also need to be seen in the national context. As shown in Figure 8.3, in most countries, the proportion of habitat types in favourable status is higher within mountains than outside them, sometime by a very significant margin in countries with large mountain areas (for example, Austria, Greece, Italy) and those with small mountain areas (for example, Finland, Sweden, Poland). The only countries for which this trend does not hold true are in the British Isles: Ireland and the United Kingdom.

Table 8.6 Numbers of habitat types in each massif classified by conservation status

	FV	U1	U2	XX	Total
Apennines	47	26	3	8	84
Balkans/South-east Europe	32	27	23	1	83
Atlantic islands	11	12	7	1	31
Nordic mountains	22	13	27	2	64
Central European middle mountains 1 *	16	18	12	2	48
Eastern Mediterranean islands	13	18	6	8	45
Carpathians	10	21	18	2	51
Alps	14	37	35	7	93
French/Swiss middle mountains	11	22	37	7	77
Western Mediterranean islands	7	17	14	15	53
Central European middle mountains 2 **	4	15	32		51
Pyrenees	3	19	30	36	88
British Isles	1	7	52	4	64
Iberian mountains		6	3	77	86
Total mountains	**191**	**258**	**299**	**170**	**918**

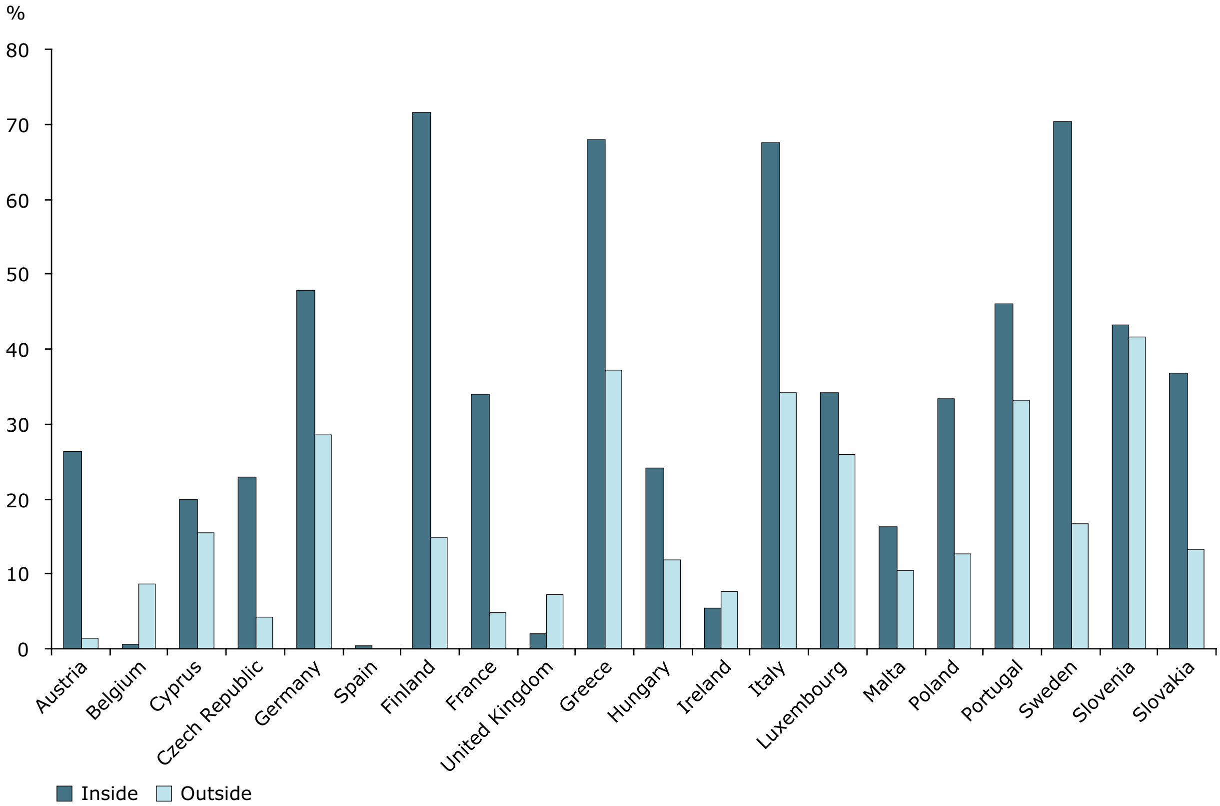
Note: * = Belgium and Germany; ** = the Czech Republic, Austria and Germany.
FV = Favourable, U1 = Unfavourable — inadequate, U2 = Unfavourable — bad, XX = Unknown.

Figure 8.2 Proportions of habitat types in each massif classified by conservation status



Note: * = Belgium and Germany; ** = the Czech Republic, Austria and Germany.

Figure 8.3 Habitats in favourable conservation status in EU Member States, inside and outside mountain areas



8.2 Birds and their habitats

Mountain areas provide important habitats for many bird species. Mountain ranges can also be significant bottlenecks to migration (Heath and Evans, 2000), which is a key issue as populations of long-distance migrants are 'declining alarmingly' (BirdLife International., 2004b; Sanderson *et al.*, 2006); their water bodies and associated wetland and grassland ecosystems are critical resting sites (Box 8.1). Under Article 12 of the Birds Directive, EU Member States are required to report on its implementation on a three-yearly basis. However, the most recent period for which reports have been consolidated is 1999–2001 (EC, 2006), and relatively few species with distributions primarily in mountain areas are listed in its Annex I as in danger of extinction, rare, vulnerable to specific changes in their habitat or requiring particular attention for reasons of the specific nature of their habitat. The relatively small number of mountain species listed in Annex I may be one reason that knowledge about them is often particularly lacking; it has also been suggested that there is a greater interest in mammals than in birds in alpine regions (Thompson, 2003). Complementing the Birds Directive, under which Special Protection Areas (SPAs) have been identified, BirdLife International has prepared an inventory of Important Bird Areas (IBAs) using comparable scientific criteria. The total area of IBAs is greater than that of SPAs; the latter cover only 44 % of the total area of IBAs (BirdLife International, 2010).

The identification of IBAs is based around habitats (Tucker and Evans, 1997; Heath *et al.*, 2000). Of these, a small number can be unequivocally identified as occurring in mountain areas. Tucker and Evans (1997) distinguish four such habitat types within broader habitats:

- boreal and temperate forests: montane forests (widely distributed across different mountain areas);
- agricultural and grassland habitats: montane grassland (widespread in the Alps, Carpathians and Pyrenees and mountain ranges to their south, including in Turkey);
- tundra, mires, and moorland: boreal montane (almost all in the Nordic mountains), moorland dominated by *Calluna* (at lower altitudes in the mountains of Norway, and covering much of the mountains of the British Isles).

Box 8.1 Karst poljes in the Dinarides and their significance for water bird conservation

The Dinaric Karst is the most extensive, continuous karst area in Europe (Gams, 1974). This huge mountain fringe from Slovenia to Albania, approximately 800 km long and up to 150 km wide, is interspersed by extensive depressions or karst poljes. They are often covered by wetlands and extensive periodically flooded grasslands, which harbour significant resting sites and nesting habitats for water and grassland birds (cf. Valvasor, 1689; Reiser, 1896, 1939; Kmecl and Rizner, 1993; Polak, 1993, 2000). They are of great conservation value for both European bird populations and western Palearctic migrants (Schneider-Jacoby *et al.,* 2006; Stumberger *et al.*, 2008).

Photo: © Peter Sackl
Migrating spoonbills in front of the Prokletije Massif, Bojana-Buna Delta, Albania.

As the seasonality, duration and extent of flooding limit land use, large areas of the karst poljes are traditionally used as temperate grassland. The occurrence and numbers of the water birds depends on the flooding (Schneider-Jacoby, 1993, 2005). There are at least 139 karst poljes, of which 44 are classified as dry, 48 as rarely inundated, and 47 as frequently flooded. With a total area of 3 056 km^2, the surface area varies from 0.2 to 408 km^2. Seasonal flooding occurs on about 2 745 km^2 (90 %) of the total area of the karst poljes, but only 1 547 km^2 (51 %) are regularly flooded for longer periods.

Two billion birds from Eurasia winter in the Sahel, the transition zone between the Sahara desert and the Sudanian savannas (Zwart *et al.*, 2009). During migration to their winter quarters and back to their breeding areas, many cross large areas unsuitable for resting, such as the Sahara and the Mediterranean Sea. Some species, such as common cranes *(Grus grus)*, use discrete migration corridors; others, such as Eurasian spoonbills *(Platalea leucorodia*) use traditional resting sites in narrow front migration (Berthold, 2000). For trans-Mediterranean migrants that cross the central Mediterranean (Schneider-Jacoby, 2008), the mountain ridges and dry highlands of the Dinaric Karst represent a considerable additional barrier after the sea and the desert. During the return passage after crossing the Adriatic Sea, suitable resting sites are rare along the mostly rocky shore (Smit, 1986; Stipčević, 1997) and 80 % are heavily impacted (Willinger and Stumberger, 2009); the karst poljes offer vital resting sites.

Studies of bird migration on periodically flooded karst poljes — Cerkniško polje in Slovenia (Kmecl and Rizner, 1993) and the largest polje, Livanjsko polje, Bosnia and Herzegovina (Stumberger *et al.*, 2008) — and analyses of ringing data indicate that the Dinaric Karst is frequented by populations from central and northeastern Europe and migrants from western and northwestern Siberia. The karst poljes are key resting sites along major migration routes (Scott and Rose, 1996), for the Western Siberian/Black Sea–Mediterranean populations of ducks, geese, swans and waders. Current estimates of the population trends of water birds that migrate through the Dinaric Karst, mostly in SW–SSW directions, indicate long-term declines for 33 species (Table 8.1). Some species that use the Adriatic flyway, such as slender-billed curlew *(Numenius tenuirostris)*, are already on the brink of extinction (Wetland International, 2006). The significance of the karst poljes for bird migration and the conservation of Eurasian water birds has been largely overlooked, as bird hunting seems to be a major impact and large concentrations of resting birds are lacking in most poljes (Schneider-Jacoby, 2008; Schneider-Jacoby and Spangenberg, 2009; Stumberger *et al.*, 2009).

Photo: © Borut Stumberger
Livanjsko polje, Bosnia and Herzegovina, during winter floods 2009.

Source: Borut Stumberger and Martin Schneider-Jacoby (EuroNatur, Germany).

For each habitat type, further information is provided on ecological characteristics; values, roles and land uses; and influencing political and socioeconomic factors. Similarly, various requirements are listed for individual priority species. With regard to conservation status, for the boreal montane and moorland habitats, statements relate only to the broader habitats, so it is generally not possible to be more specific about the status of, and threats to, these species specifically in mountain areas. For the other two habitat types, priority birds, all with unfavourable conservation status, are listed, together with threats. There are 46 priority species in montane forests, with an increase in the species richness of breeding priority birds from west to east, with the highest numbers in Romania, Slovakia and Slovenia; and also in France. Over a 20-year timeframe, widespread threats to these forests (affecting at least 10 % of the total habitat type) were judged to be inappropriate forest management and overgrazing; regional threats (1–10 % of the total habitat type) were logging, habitat fragmentation, air pollution and severe or frequent fires. In montane grassland, there are 33 priority species, of which a third are dependent on this habitat type in Europe. Comparably, widespread threats were high stocking levels, recreation, and atmospheric nutrient pollution; regional threats were land abandonment and reductions in livestock carcasses. There has been further research on a number of these threats, such as the impact of ski areas on high-altitude bird communities (Rolando *et al.*, 2007; Lowen, 2009); as well as the more recent threat posed by wind farms (for example, Bright *et al.*, 2008). In 2004, BirdLife International (2004a) identified 13 montane grassland species that had an unfavourable conservation status and therefore qualified as Species of European Conservation Concern. Of these, populations of three were declining, populations of seven were stable, and the status for three was unknown.

A habitat-based approach was also taken by Heath *et al.* (2000) in their comprehensive evaluation of all IBAs in Europe. One of the levels of analysis considered sites with biome-restricted species, i.e. sites 'known or thought to hold a significant assemblage of species whose breeding distributions are largely or wholly restricted to one biome' (Heath *et al.*, 2000, p. 11). There are five of these, including the 'Eurasian high-montane (alpine) biome', with 10 species restricted to this biome, which includes 14 IBAs in Switzerland, 12 in Italy, five in both Greece and Spain, two in the former Yugoslavia, and one in each of Bulgaria, France, Germany, Poland, Slovakia, Slovenia, and Turkey. Most of the analysis within this volume is for habitat types, but only one of these is unequivocally mountainous: alpine/sub-alpine/boreal grassland, which is present in 7 % (263) of the 3 619 IBAs at the time. More recent work (Huntley *et al.*, 2007) recognises biogeographical elements in Europe's avifauna, grouping species according to the overall similarity of their recorded breeding distributions recorded in 50 x 50 km grid squares. However, none of the 19 elements can unequivocally be compared to mountain areas; and Huntley *et al.* (2007) note that one of the two groups whose geographical distribution could not be modelled using this approach comprised species whose distributions were restricted to areas of very high relief, given the relatively coarse resolution of both distribution data and climatic data (cf. Section 5.2). In summary, while information is available regarding the distribution of, and threat to, priority bird species and the habitats of IBAs, and of the distribution of bird species in general (for example, BirdLife International, 2004a), further work needs to be done to evaluate both distributions and threats specifically in Europe's mountain areas.

8.3 Impacts of climate change

Mountain species and habitats are subject to many stresses and vulnerabilities due to anthropogenic factors, including land-use practices and changes, freshwater abstraction, tourism and recreation, infrastructure development, the introduction and expansion of alien species (Box 8.2), and air and water pollution (Huber *et al.*, 2005; Nagy and Grabherr, 2009; Price, 2008). Increased concentrations of atmospheric CO_2, the primary cause of climate change, may eventually have significant impacts on alpine plant biodiversity because of species' differential responses (Körner, 2005). The likely changes in the climate of Europe's mountains, outlined in Chapter 5, will influence their biota both directly and indirectly, for instance through changes in the availability of water, as discussed in Chapter 6. For vegetation, the two main climatic drivers are temperature and precipitation. More emphasis is usually placed on temperature because, as discussed in Chapter 5, there is more consistency in prediction. Various model-based studies of changes in vegetation have been undertaken, often with temperature as the sole driving factor (Nagy and Grabherr, 2009). However, precipitation is also an important factor, and observed changes in precipitation in the Alps have already been associated with changes in vegetation (Cannone *et al.*, 2007).

Box 8.2 Alien plants in the Alps: status and future invasion risks

Alien (or non-native) species occur outside their native range only because of human-mediated dispersal. Among them, invasive alien species are those which spread rapidly in their new range and may have a negative impact on native biodiversity or lead to other economic costs. In the Alps, some 450 to 500 alien vascular plant species have been recorded (Aeschimann *et al.*, 2004): approximately 10 % of the total flora of the Alps (Aeschimann *et al.*, 2004) and 15 % to 20 % of all alien plant species recorded in Europe (Pysek *et al.*, 2008). However, the number of recorded alien plants is increasing rapidly in Europe (Pysek *et al.*, 2008) and probably also in the Alps. Most alien plant species in the Alps occur only at low elevations. A comprehensive survey along roadsides in the Swiss mountains showed that only about 90 out of 155 recorded alien plants were found above 1000 m, approximately 50 species above 1 500 m, and approximately 10 species above 2 000 m (see photo below); and that species that are more abundant and/or present for a longer time in lowlands tend to reach higher elevations (Becker *et al.*, 2005). Among the major invasive plant species of the European lowlands (Wittenberg, 2005), 23 occur in the montane zone, of which nine reach the subalpine zone (Table 8.7). At higher elevations, none of these species is known to have a strong negative impact on biodiversity or other human values.

The relative resistance of mountain ecosystems to plant invasions may be transient in the light of ongoing global change (Pauchard *et al.*, 2009). The paucity of alien species in mountains is partially related to the historic introduction process. Alien species were introduced to the lowlands and had to survive in lowland climates and habitats before they could spread to higher elevations. This low-altitude filter effect (Becker *et al.*, 2005) limited alien species found at higher elevations to climatically broadly adapted species that can occur across the complete altitudinal range (MIREN [Mountain Invasion Research Network], unpublished data). Increasingly, however, alien plants are directly introduced from one high elevation region to another, especially through the horticultural plant trade. These alien mountain specialists are pre-adapted to high-elevation climates and are expected to pose a greater invasion risk in mountains. The relative resistance of mountain ecosystems to plant invasions may also weaken in the future through other global change processes, in particular climate change and the expansion of anthropogenic disturbances. Invasive plants from lower elevations (Table 8.7) may move to higher elevations in a warming climate, and anthropogenic disturbances generally facilitate plant invasions.

Prevention is considered the most cost-efficient management strategy against the threats posed by invasive species. Globally, the Alps are one of few eco-regions not yet badly affected by plant invasions, but this may change. Now is thus the time to act to prevent future invasions: probable invasive species should be identified, and their transportation regulated. Species that have proven problematic in other mountain areas are particularly likely to become invasive, and MIREN (2010) has developed an online database of invasive plant species in mountains worldwide. However, most species currently listed in the database are native to Europe and thus, based on past invasions, only few potentially invasive alien species can be predicted for the Alps (Table 8.7). A threat may rather be expected from future introductions from novel source areas (for example, the very species-rich mountain region of Yunnan in China).

The establishment of ecological corridors will probably not increase the risk of the unassisted spread of most alien plants, because they mainly spread in anthropogenic habitats and through human movements. However, alien species can be transported accidentally between protected areas of an ecological network by tourists or natural area managers. Codes of conduct on the cleaning of clothes, tools and machines before entering natural areas may reduce the risk of spreading alien species. Networks of institutions and experts associated with ecological corridors represent an important institutional capacity for coordinating monitoring and control of these species.

Photo: *Lupinus polyphyllus*, native to western North America, reaches the subalpine zone in the European Alps where it occasionally forms monospecific stands.
The picture shows the species next to the Furka pass road in Switzerland at about 2 100 m above sea level.

Source: Christoph Kueffer (Institute of Integrative Biology, ETH Zurich, Switzerland) with contributions from Jake Alexander, Hansjörg Dietz, Keith McDougall, Andreas Gigon, Sylvia Haider and Tim Seipel (MIREN).

Box 8.2 Alien plants in the Alps: status and future invasion risks (cont.)

Table 8.7 Potentially invasive plants of higher elevations in the European Alps

Genus	Species	Family	Elevation
Acacia	*dealbata* ([1])	Fabaceae	colline ([12])
Ambrosia	*artemisiifolia* (*)	Asteraceae	colline ([12])
Artemisia	*verlotiorum* (*)	Asteraceae	montane
Buddleja	*davidii* (*)	Buddlejaceae	montane
Bunias	*orientalis* (*)	Brassicaceae	montane
Caragana	*arborescens*	Fabaceae	no data
Conyza	*canadensis* (*)	Asteraceae	subalpine
Elodea	*canadensis* ([2],*)	Hydrocharitaceae	subalpine
Epilobium	*ciliatum* (*)	Onagraceae	montane
Erigeron	*annuus* (*)	Asteraceae	montane
Fagopyrum	*esculentum*	Polygonaceae	montane
Fagopyrum	*tataricum* ([3])	Polygonaceae	subalpine
Heracleum	*mantegazzianum* ([4],*)	Apiaceae	subalpine
Hordeum	*jubatum*	Poaceae	montane
Impatiens	*glandulifera* ([5],*)	Balsaminaceae	montane
Impatiens	*parviflora* (*)	Balsaminaceae	subalpine
Juncus	*tenuis* (*)	Juncaceae	subalpine
Lupinus	*polyphyllus* (*)	Fabaceae	subalpine
Matricaria	*discoidea* (*)	Asteraceae	subalpine
Mimulus	*guttatus* (*)	Scrophulariaceae	montane
Papaver	*croceum* ([6])	Papaveraceae	alpine
Pinus	*strobus* ([7])	Pinaceae	montane
Polygonum	*nepalense* ([8])	Polygonaceae	montane
Polygonum	*polystachyum* (*)	Polygonaceae	colline ([12])
Prunus	*laurocerasus* (*)	Rosaceae	montane
Reynoutria ([9])	*japonica* (*)	Polygonaceae	montane
Reynoutria ([9])	*sachalinensis* (*)	Polygonaceae	subalpine
Robinia	*pseudoacacia* (*)	Fabaceae	montane
Sedum	*spurium* ([10],*)	Crassulaceae	montane
Senecio	*inaequidens* (*)	Asteraceae	montane
Senecio	*rupestris* (*)	Asteraceae	alpine
Solidago	*canadensis* ([11],*)	Asteraceae	montane
Solidago	*gigantea* ([12],*)	Asteraceae	montane

Note: The table includes species that are recognised invaders in a European country (Wittenberg, 2005; DAISIE, 2010) and occur in the montane zone or higher in the European Alps (Aeschimann *et al.*, 2004); and species that are, on a species or genus level, invasive in mountains outside of Europe (MIREN, 2010). Priority invasive species in Europe are indicated in bold.

(*) Listed as an invasive species for lowland areas in Europe (Wittenberg, 2005); ([1]) a subspecies *subalpina* has been described in Australia; ([2]) aquatic plant; ([3]) synonym: *Polygonum tataricum*, ([4]) and other alien *Heracleum* species; ([5]) syn*: Impatiens taprobanica*; ([6]) syn*: Papaver nudicaule*; ([7]) and other alien *Pinus* species; ([8]) syn*: Persicaria nepalensis*; ([9]) syn: *Fallopia*; ([10]) syn: *Phedimus spurious*; ([11]) syn: *Solidago altissima*; ([11]) syn: *Solidago serotina*; ([12]) experts believe the species has the potential to reach higher elevations.

Research in Austria, Norway and Switzerland has shown increasing numbers of plant species on many summits (Parolo and Rossi, 2008), and the Global Observation Research Initiative in Alpine Environments (GLORIA: Box 8.3) has been designed to monitor this process. A likely impact of climate change is upslope migration of vegetation climatic belts, generally — but not always — leading to a decrease in their area, and the loss of the coldest climatic zones at the summits. Migration of habitats around mountains to a different aspect may also be possible. Yet migration is typically severely restricted as a spatial response in mountain areas because of their topography and, often, both the availability of suitable soils and past and present land uses (Theurillat and Guisan, 2001). Thus upslope migration will probably result in the contraction and fragmentation of populations of plants and fauna in present montane, alpine and nival belts.

Box 8.3 Climate change and Europe's alpine plant diversity: the GLORIA long-term observation network

Biota living in high mountain environments, i.e. the alpine area from the tree line ecotone upwards and the nival zone above the closed dwarf alpine vegetation (Nagy and Grabherr, 2009), are exposed to and governed by low-temperature conditions and should respond sensitively to climate warming. There is growing evidence of increased plant species richness at alpine and nival observation sites resulting from upwards range expansions induced by warming (for example, Grabherr *et al.*, 1994; Klanderud and Birks, 2003; Britton *et al.*, 2009). An acceleration of this process during the exceptionally warm years of the past decades has been found by Walther *et al.* (2005) in the Swiss Alps. Concurrently, enhanced tree growth at the tree-line ecotone and the encroachment of trees into the alpine zone has been documented (Moiseev and Shiyatov, 2003; Kullman and Öberg, 2009).

Model studies show diverging projections, ranging from potential species losses of around 60 % in some European mountain regions within this century, based on coarse grid cells across Europe (Thuiller *et al.*, 2005) to fine-scaled approaches resulting in a persistence of up to 100 % of habitats of high mountain species in a regional case study in one of the highest parts of the Alps in Valais, Switzerland (Randin *et al.*, 2009). Other local-scale models project severe contractions of the habitats of nival species (Schrankogel, Tyrol, Austria: Gottfried *et al.*, 1999) and of the alpine zone in an outer and lower mountain range where many endemic species dwell (northeast Alps), with a temperature increase of + 2 °C (Dirnböck *et al.*, 2003). However, some subalpine to alpine biota, such as *Pinus mugo* communities, might be very resilient and could delay invasion of new competitors from lower elevations (Dullinger *et al.*, 2004).

The diverging model predictions on the fate of alpine biodiversity reflect different spatial and temporal scales and resolutions, different interpretations, but particularly gaps in knowledge about the potential of species to keep pace with climate warming. Systematic, coordinated, and long-term monitoring approaches that endeavour to fill this gap have only recently been implemented. One successful monitoring approach is the Global Observation Research Initiative in Alpine Environments (GLORIA), which began in Europe at the turn of the millennium through the EU FP-5 project GLORIA-Europe in 18 mountain regions (Grabherr *et al.*, 2001). The observation network now includes sites on five continents, with permanent monitoring sites in more than 75 mountain regions (GLORIA, 2010a) and continues to expand.

In terms of both comparability and cost, the basic approach of GLORIA focuses on summit areas as being easily locatable sites for resurveys that enclose all aspects within a small area. On summits, shading effects from neighbouring land features are minimised and, due to the absence of escape routes, they may act as climate warming traps for cold-adapted species with weak competitive abilities. Four such summit sites are established along an altitudinal gradient in each region from the tree-line ecotone to the uppermost vegetated zone available (Pauli *et al.*, 2004). On each summit site, all vascular plant species (cryptogams optional, dependent on the availability of experts) are recorded at spatial scales ranging from the entire summit area (within the uppermost 10 m of vertical distance), the 10 m x 10 m level, down to 1 m x 1 m and 0.1 m x 0.1 m levels. Dependent on the plot size, species abundance, species cover using a line-point method, visual cover estimation, and fine-scaled species frequency are recorded (GLORIA, 2010b). Continuous measurements of soil temperature at 10 cm below the surface at the four cardinal directions on each summit are used to compare changes in temperature and snow regimes. Resurveys are to be made at intervals of 5 to 10 years. A higher recording frequency would risk enhanced damage caused by the observers and be of limited importance, as most alpine plants are long-lived and slow-growing.

Box 8.3 Climate change and Europe's alpine plant diversity: the GLORIA long-term observation network (cont.)

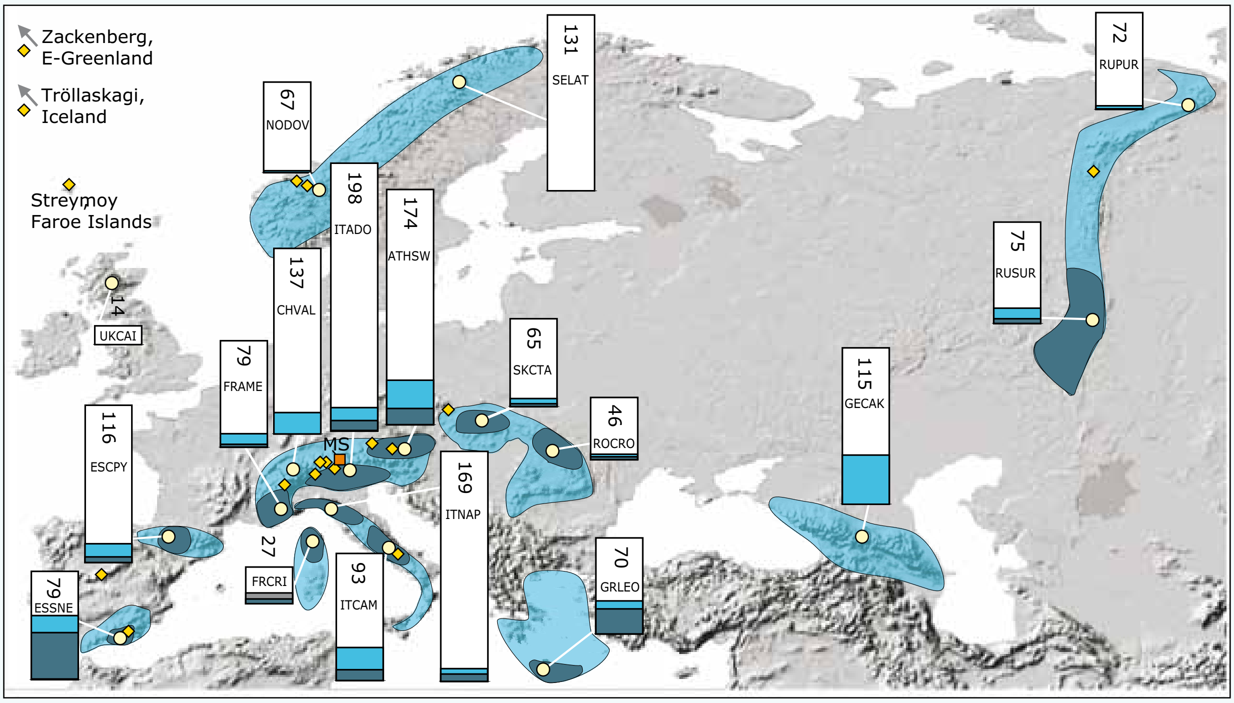
Data from the European GLORIA sites show pronounced differences in vascular plant species richness, ranging from 14 species (Cairngorms, Scotland) to around 200 (southern Alps, Dolomites, Italy) per GLORIA target region (species of all four summits pooled). While the greatest species richness is in the calcareous Alps, the Mediterranean mountains have the highest percentage of endemic species (Figure 8.4). The proportion of endemics in Mediterranean mountains such as the Majella (central Apennines; (Stanisci *et al.*, 2005) and the Sierra Nevada (Spain) increases with altitude; most of the locally distributed species are restricted to high elevations (Pauli *et al.*, 2003). With regard to species threatened by extinction, Mediterranean mountains appear to be particularly vulnerable. The marginal mountain ranges of the Alps, hosting alpine refugia of locally restricted plants (Essl *et al.*, 2009) may be in a similar situation.

In 17 out of the 18 GLORIA-Europe target regions (Figure 8.4) resurveys were conducted seven years after setting the baseline. Data from 2001 and 2008 are being used to develop a Europe-wide indicator for the impacts of climate change on alpine plant diversity in cooperation with the European Topic Centre of Biological Diversity and the European Environment Agency. This may already be sensitive enough to detect shifts of species composition in relation to the thermal preferences.

While warming-induced extinction process in Europe's mountains are not yet expected to be discernible within the short period of seven years, observations at Schrankogel indicate a range contraction of the most cryophilic plant species (Pauli *et al.*, 2007). At the alpine–nival ecotone, several pioneer species of alpine grassland were increasing in cover, while all of the true nival species declined over 10 years (Figure 8.5).

Source: Harald Pauli, Michael Gottfried and Georg Grabherr (Department of Conservation Biology, Vegetation and Landscape Ecology, University of Vienna, Austria) and partners from the GLORIA-Europe Network.

Figure 8.4 The GLORIA target regions in Europe



The GLORIA target regions in Europe

- ○ GLORIA-Europe target region (setup in 2001)
- ◇ More recent target region (setup between 2003 and 2009)
- ■ MS: GLORIA Master Site Schrankogel (Tyrol, Austria)

991 taxa (spp. and subspp.)

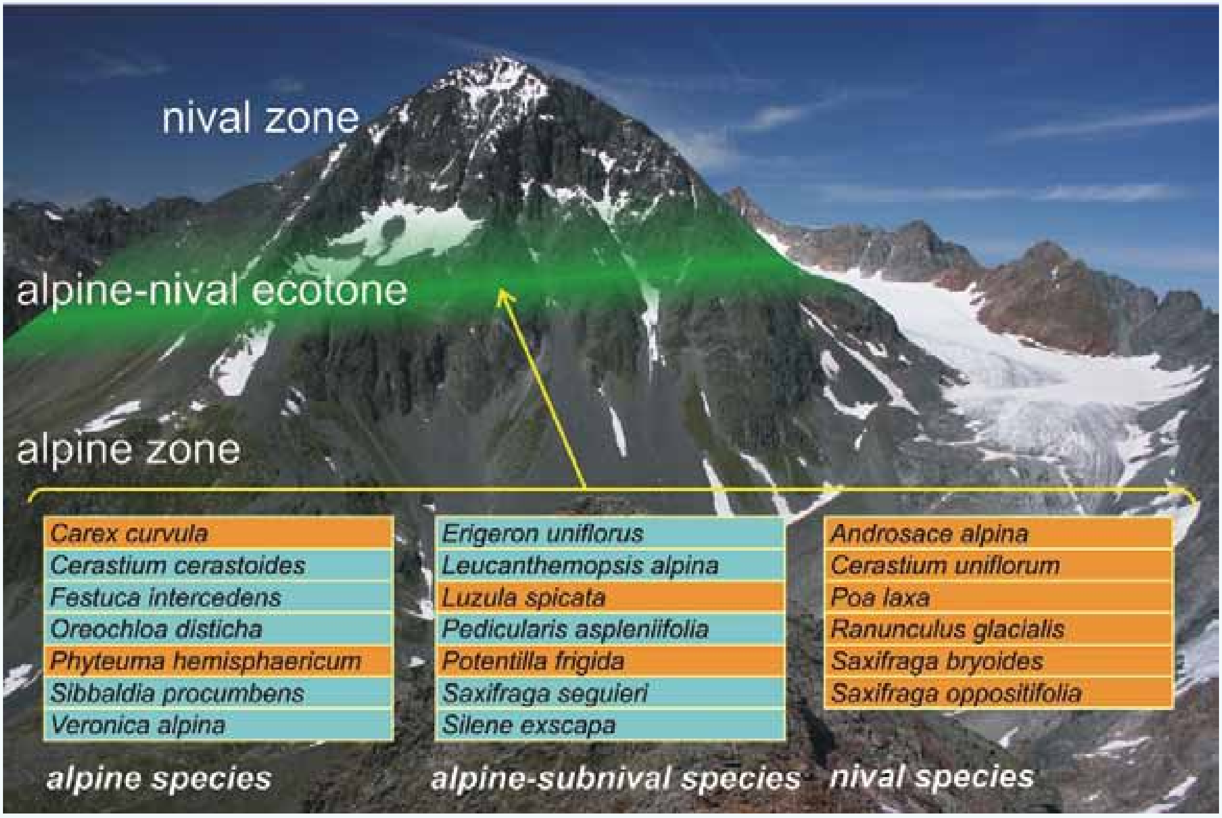
248 taxa endemic s.l.

99 taxa endemic s.str.

Box 8.3 Climate change and Europe's alpine plant diversity: the GLORIA long-term observation network (cont.)

Vascular plant species richness (total and endemic species; data pooled from four summit sites per region) is shown for the initial 18 GLORIA-Europe regions. Colours indicating the proportion of endemic species (endemics in the wider sense, light blue; in the strict sense, dark blue) correspond with the homochromatic distribution areas around a particular region.

Figure 8.5 The high-elevation GLORIA master site Mount Schrankogel (Tyrol, Austria)



Note: The alpine–nival ecotone (approximately 2 900–3 200 m) is the transition zone between the upper alpine grassland zone and the rock-, scree- and snow-dominated nival zone, where vegetation disintegrates into open plant assemblages. Data from 362 permanent plots across the ecotone showed significant differential cover changes of 20 species (out of a total of 59) in relation to their vertical distribution ranges (blue: increase in cover, orange: decrease in cover).

Source: Pauli *et al.*, 2007.

During the present century, it is likely that Europe's mountain flora will undergo major changes due to climate change (Theurillat and Guisan, 2001; Walther, 2004). Change in snow-cover duration and growing season length should have much more pronounced effects than direct effects of temperature changes on metabolism (Grace *et al.*, 2002; Körner *et al.*, 2003). Overall trends are towards increased growing season, earlier phenology and shifts of species distributions towards higher elevations (Kullman, 2002; Körner *et al.*, 2003; Egli *et al.*, 2004; Sandvik *et al.*, 2004; Walther, 2004; Casalegno *et al.*, 2010). Similar shifts in elevation are also documented for animal species (Hughes, 2000). However, the spatial scale of modelling can strongly influence the predicted persistence of suitable habitats (Trivedi *et al.*, 2008; Randin *et al.*, 2009). Recent phenological work in the Alps suggests a stronger advance of flowering phases at high altitudes, with a tendency towards a stronger altitudinal response in the northern than in the southern Alps (Ziello *et al.*, 2009).

The pattern of succession and change in upland forest ecosystems with climate change could also be driven by changes to the frequency and intensity of the natural fire cycle. In the period from May to October, the proportion of lightning fires changed from an average of 20.3 % in the 1980s to 29.1 % in the 1990s, and 41.1 % in the 2000s for areas of the Swiss Alps (Box 5.3). As climate change may lead to an increased frequency of hot and dry summers (Schär *et al.*, 2004), these results suggest that, in the future, lightning-induced fires may assume a significant ecological role and have a higher economic impact in the Alps.

Many northern hemisphere tree lines have shifted upwards (Rosenzweig *et al.*, 2007), and it is predicted that the eventual shift may be several hundred metres (Badeck *et al.*, 2004). There is evidence that this process has already begun in Scandinavia (Kullman, 2002; Box 8.4), the Ural Mountains (Shiyatov *et al.*, 2005), West Carpathians (Mindas *et al.*, 2000) and the Mediterranean (Peñuelas and Boada, 2003; Camarero and Gutiérrez, 2004; Jump *et al.*, 2007). In the Alps and Carpathians, the potential area of broadleaved tree species is expected to increase relative to conifers (Lexer *et al.*, 2002; Skvarenina, *et al.*, 2004). In the Montseny Mountains in Spain, the distributions of *Quercus ilex* and *Fagus sylvatica* have already shifted towards higher elevations during recent decades (Peñuelas *et al.*, 2007). The tree line will also rise where suitable microsites become available as a result of decreased tree mortality and increased growth and reproduction where temperature is currently limiting. For example, upward movement of tree lines dominated by *Picea abies* and *Pinus cembra* in the Alps has already been observed. However, tree lines are sensitive not only to changes in climate but also to changes in land use, which may either offset or amplify climatic effects (Gehrig-Fasel *et al.*, 2007). In particular, the level of grazing by both wild and domestic herbivores is a significant factor (Hofgaard, 1997; Stutzer, 2000).

The possible combination of these types of changes, together with the effect of abandonment of traditional alpine pastures, will restrict the alpine zone to higher elevations (Guisan and Theurillat, 2001; Grace *et al.*, 2002; Dirnböck *et al.*, 2003; Dullinger *et al.*, 2004), severely threatening nival flora (Gottfried *et al.*, 2002). The composition and structure of alpine and nival communities are very likely to change (Guisan and Theurillat, 2000; Walther, 2004). Local plant species losses of up to 62 % are projected for Mediterranean and Lusitanian mountains by the 2080s under the A1 scenario (Thuiller *et al.*, 2005).

Overall, mountain ecosystems are among the most threatened in Europe (Schröter *et al.*, 2005). This relates not only to direct impacts of changing climate, often compounded by changes in land use, but also, especially for birds, to indirect impacts. For example, changes in the availability of key food species may affect the abundance of insectivorous birds, such as golden plover (*Pluvialis apricaria*), as suggested by research based on recent temperature trends and climate modelling (Pearce-Higgins *et al.*, 2009). Their main prey species, tipulids, are also important prey for a wide range of species, particularly other waders (Buchanan *et al.*, 2006), whose populations would be similarly affected.

For both flora and fauna, high-latitude and -altitude countries are likely to have a greater proportion of species colonising suitable climatic areas than the remaining European countries where more species are expected to lose suitable climate space. Therefore high-latitude and -altitude countries may gain species at the expense of the loss of cold-adapted species, some of which are narrow endemics (Araújo, 2009). Measures to ensure the long-term survival of populations of species affected by climate change are considered in Section 9.3.

Box 8.4 Recent changes of vegetation pattern in the mountains of northern Sweden

Arctic and subarctic alpine landscapes are currently undergoing substantial changes in plant community structure, mainly due to increasing temperatures and a prolonged snow-free season. Observed changes include advancing tree lines, increasing shrub cover in the treeless tundra, and the decreasing area of long-lasting snowbeds (Björk and Molau, 2007; Huntley *et al.*, 2000; Kullman, 2002; Sturm *et al.*, 2001; Sundqvist *et al.*, 2008). Recent synthesis efforts within the circumpolar ITEX (International Tundra Experiment) network emphasise a shift in dominance among species as the main short-term (3–5 years) response to experimental warming; species turnover requires longer-term exposure to a shifting climate regime (Walker *et al.*, 2006).

The basic ITEX research programme includes moderate warming of experimental plots employing open-top chambers to enhance surface temperature by 1–3 °C (ITEX, 2010). A number of variables (for example, plant community structure, cover, growth and phenology) have been assessed at intervals from one to several years in experimental plots and their associated non-manipulated controls. Time series of at least 10 years are now available for vegetation at most of the approximately 20 ITEX sites in the arctic and alpine tundra around the world.

The Swedish ITEX site was established at Latnjajaure Field Station in the mountains of northernmost Swedish Lapland (68 ° 21' N, 18° 30' E) in May 1992 (see photo below). The site is in the mid alpine zone at 1 000 m and has a floristic composition typical of the low Arctic. From 1992 to 2009, the annual mean air temperature increased significantly at about 0.1 °C/year (Björk *et al.*, 2007; Figure 8.6). Studies have both been at the landscape level and have focused on typical subarctic–alpine plant communities; for example, dry and mesic heaths and meadows, wet sedge communities, tussock tundra, moderate snowbeds, and calcareous cliff ecosystems. The results are consistent across ecosystems, with an increase in boreal species that tend to gradually out-compete alpine species. Forerunners of an advancing tree line are established as ≤ 30-yr-old treelets of mountain birch (*Betula tortuosa*) at altitudes up to 500 m above the current forest line at 700 m (Sundqvist *et al.*, 2008). The highest outpost trees, some < 1.5 m tall and anticipated to reach fertility and seed production within a few decades, are on cliff ledges with a favorable microclimate, protected against winter grazing by hares. The advancing mountain birch is accompanied by other boreal plant species; for example, blueberry (*Vaccinium myrtillus*), lingonberry (*V. vitis-idaea*) and the grass *Dechampsia flexuosa*. An increase in shrubby willows (*Salix spp*.) has been observed in moist meadows, tussock tundra, and snowbed meadows. In the tussock tundra dominated by Arctic cottongrass (*Eriophorum vaginatum*), the cover of lingonberry increased by about 100 % in the experimental warming and 50 % in the control plots over a 12-year period, concurrent with degrading permafrost (Molau, in press).

Photo: © Ulf Molau
Latnjajaure Field Station, Sweden. Viewed from the south-west. Open-top chambers in a dry-death ecosystem and a point-frame for sampling are seen in the foreground (photo taken 7 August 2008).

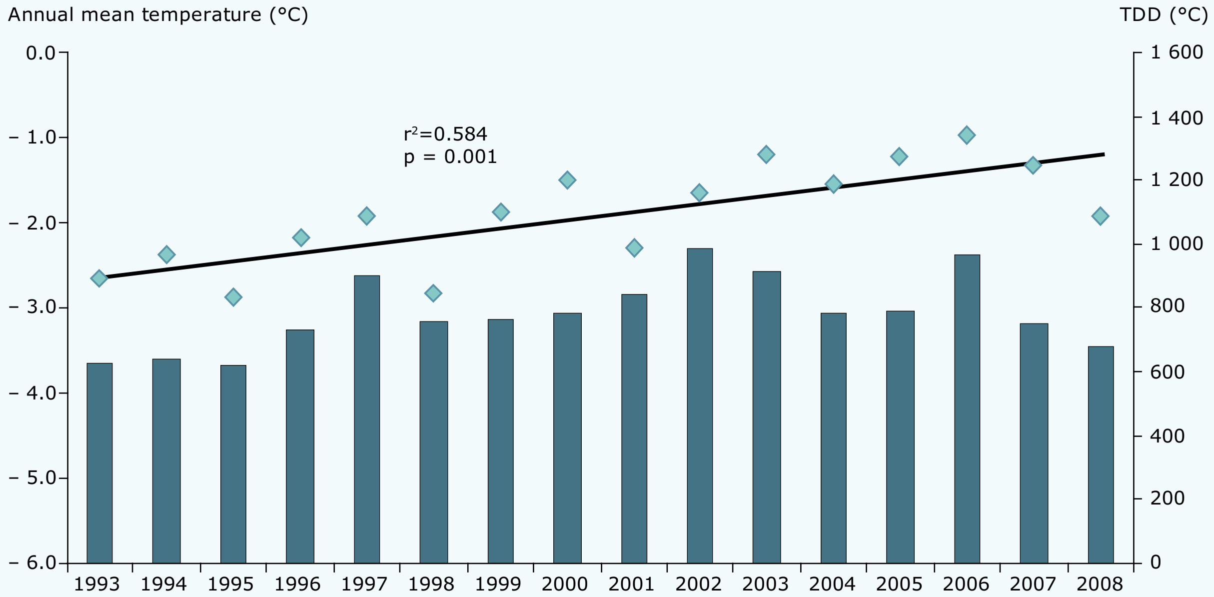
These changes in alpine vegetation pattern are in good accordance with changes observed in recent decades in the southern Scandes in mid-Sweden (Kullman, 2002), especially with regard to the altitudinal advance of mountain birch and other boreal species. The increase in shrub cover (Jägerbrand *et al.*, 2009) parallels observations from low-arctic Alaska (cf. Sturm *et al.*, 2001). Few plant species have been recorded as new to Latnjajaure as a result of climatic warming — apart from the sub-alpine willow *Salix phylicifolia*, established as saplings in snowbed meadows during the past decade.

Box 8.4 Recent changes of vegetation pattern in the mountains of northern Sweden (cont.)

Overall, monitoring of vegetation structure, species composition and species-specific performance in the ITEX network provides a reliable forecast that may assist in modelling future vegetation in alpine landscapes under climate warming, with associated changes in physiognomy and species richness. Aims and targets for the programme of work on mountain biodiversity under the UN Convention on Biological Diversity (CBD, 2010) are far from being reached as outlined in agreed protocols and *in situ* conservation of specialist alpine plant species may become increasingly hard to achieve.

Source: Ulf Molau (Department of Plant and Environmental Sciences, University of Gothenburg, Sweden).

Figure 8.6 Annual mean air temperature (dots and regression line) and thawing degree days (TDD; bar plot)



Note: i.e. temperature sum > 0 °C, from May to September at Latnjajaure, northern Sweden, 1993–2008.

Source: Modified from Björk *et al.*, 2007.

9 Protected areas

The history of protected areas in the mountains of Europe goes back many centuries. For forests, reasons for protection include spiritual and religious motivations; hunting, with areas reserved from the medieval period by noblemen and royalty; and limiting the risks of natural hazards, with the first protective forests being declared by communes in Switzerland from the late 13th century (Price, 1988; Welzholz and Johann, 2007). Such designations recognised cultural, provisioning and regulating ecosystem services provided by mountain areas (see Chapter 4). From the 19th century, the protection by nation-states of specific areas of land specifically for their environmental qualities — often in supposedly 'pristine' environments that were actually cultural landscapes — began with the designation of Yellowstone National Park in the USA. Around the world, most of the first national parks were created in mountain areas; in Europe, the first were in Sweden, where six of the eight national parks designated in 1909 are in mountain areas. The International Union for the Conservation of Nature (IUCN) defines a protected area as 'A clearly defined geographical space, recognised, dedicated and managed, through legal or other effective means, to achieve the long-term conservation of nature with associated ecosystem services and cultural values' (Dudley, 2008). Thus, as noted by Stolton and Dudley (2010), most protected areas are managed — and increasingly so — to provide multiple ecosystem services to diverse communities. Protected areas recognised by the IUCN now cover 12.9 % of the Earth's land surface (IUCN and UNEP-WCMC, 2010). In addition, considerable areas of mountain forest ecosystems, in Europe and elsewhere, continue to be protected specifically to ensure the provision of the regulating services they provide, but not explicitly for conservation objectives; such areas are not considered further in this chapter.

The most recent evaluation of the coverage of protected areas, as defined by the IUCN, in mountains showed that, in 2005, the proportion of the global mountain area within protected areas was 11.4 %, slightly higher than the proportion in non-mountain areas (11.0 %) (Kollmair *et al.*, 2005). In Europe, protected areas in mountains have been designated by institutions at levels from the sub-national to the global; the latter include World Heritage Sites, biosphere reserves, and sites designated under the Convention on Wetlands (Ramsar Convention). Given the fact that mountains often form the boundaries between many European countries — including much of the European Green Belt, which spans approximately 13 000 km of the former Iron Curtain from the Barents Sea in the north to the Adriatic and Black Seas in the south (Terry *et al.*, 2006) — their ecosystems have often been protected because of their military importance. Even when they are not along national frontiers, many mountain areas have also been — and continue to be — used for military purposes. In both cases, such situations present particular opportunities and challenges as political conditions change (Boxes 9.1 and 9.2).

This chapter focuses on protected areas designated at the national scale and under the Habitats and Birds Directives of the European Union (see Chapter 1). At the national level, while the primary purpose of many designations is to conserve biodiversity at the levels of ecosystems, habitats and species, other designations have a greater focus on the maintenance of specific landscapes or sustainable development. Consequently, these nationally designated areas correspond to the wide range of the categories recognised by the IUCN, from strict nature reserves (category Ia) to 'protected areas with sustainable use of natural resources' (category VI) (Dudley, 2008). As discussed in Section 9.2.2, much of the land designated within the Natura 2000 network as Special Protection Areas under the Birds Directive and as Special Areas of Conservation under the Habitats Directive is also designated by national authorities. However, these Directives focus on a narrower range of ecosystem services: specifically, their aim is to assure the long-term survival of Europe's most valuable and threatened species and habitats, as discussed in Chapter 8.

Box 9.1 Sharr Mountains — towards a transboundary ecological corridor

The south-western Balkan Peninsula is a hotspot of biodiversity. The high mountains have an outstanding richness of diversity of plant species, and are one of the last retreats of large European carnivores, such as bear, wolf and lynx. The border areas were strictly guarded for decades; some sections were among the most divisive barriers in history. They now represent some of Europe's last sites with intact natural flora and fauna.

The Sharr Mountains extend from southern Kosovo* and the northwestern part of the former Yugoslav Republic of Macedonia to northeastern Albania. The mountain system is about 80 km long and 10 to 30 km wide. It includes several high peaks (the highest, Titov Vrv, is 2 747 m) and extends to Korab Mountain (2 764 m) in the southwest and continues along the border between Albania and the former Yugoslav Republic of Macedonia as the Dešat/Deshat mountain range. The European Green Belt (Terry *et al.*, 2006) is important in this context, as an existing ecological backbone. This was partly achieved through the restrictive border controls of the recent past, which were probably stricter than anywhere else along the former Iron Curtain. In addition, the mountainous nature of the terrain contributed to biodiversity protection. The key to future protection is to protect the existing ecological infrastructure and landscape, particularly for large carnivores, and to ensure that mutually agreed management and development plans are applied across the now open boundaries.

The first attempts to protect the natural values in the region started in the former Yugoslav Republic of Macedonia (then in Yugoslavia) with the proclamation of Mavrovo National Park in 1949. With an area of 73 088 ha, it is the country's largest national park, bordering both Albania and Kosovo. The first National Park in the Sharr Mountains was established in Kosovo (then in Yugoslavia) in 1986. The Park covers approximately 39 000 ha; its boundaries are artificial, both on the border with the former Yugoslav Republic of Macedonia and along the boundary between two municipalities within Kosovo. Although Albania has made significant progress in recent years in developing a system of protected areas, the establishment of a protected area along the border with Kosovo and the former Yugoslav Republic of Macedonia remains at the planning and development stage.

After years of uncoordinated actions related to nature conservation across the borders, prospects for the future are promising. The government of the former Yugoslav Republic of Macedonia has announced that a national park protecting the Sharr Mountains and their outstanding biodiversity will be proclaimed in 2010, adjacent to Mavrovo National Park. It will cover approximately 48 000 ha and extend the area already legally protected in Kosovo. Another important initiative in the former Yugoslav Republic of Macedonia aimed at the improved coherence of protected area systems in the transboundary context is the establishment of Jablanica National Park. Once proclaimed, in cooperation with Albanian counterparts, the Park would constitute another transboundary mountain area in the region in the Jablanica-Mali e Shebenikut Mountains. Although the Park in Kosovo is facing numerous problems related to management, financing and external pressures on the environment, it is an important base for sustainable development in a region affected by poverty, high unemployment and emigration. A process heading towards enlargement of the existing Park in the municipality of Dragash/Dragaš has started and is broadly supported by multi-ethnic local communities. In Albania, the Government has prepared a proposal to designate a 'Korabi Protected Landscape' covering over 30 000 ha bordering Kosovo and the former Yugoslav Republic of Macedonia. The legal proclamation of the area is foreseen for 2012.

If all the proposed initiatives related to the establishment of a transboundary 'Sharr/Šar Planina — Korab — Deshat/Dešat' protected area in Albania, Kosovo and Macedonia are implemented, the area could cover over 250,000 ha and become one of the largest protected areas in Europe. Together with adjacent Mavrovo and Jablanica National Parks in the former Yugoslav Republic of Macedonia and protected areas to be established in the triangle between Montenegro, Albania and Kosovo, enhancing the protection of the Dinaric Alps, this region will become the biggest functional, legally protected ecological corridor in the European mountains.

* The name Kosovo has been used to refer to the territory under the United Nations Interim Administration Mission in Kosovo, established in 1999 by the UN Security Council resolution 1244.

Source: Tomasz Pezold and Lee Dudley (IUCN Programme Office for South-Eastern Europe, Serbia).

Box 9.2 Reconstructing a protected area — the restoration of the Hjerkinn firing range in Dovre-Sunndalsfjella, Norway

In 2002, Dovre National Park in southern Norway was expanded into the much larger Dovre-Sunndalsfjella National Park. The former park had coexisted with a controversial neighbour for decades. Since the 1920s, the Hjerkinn military firing range had been used for extensive military field training. In 1999, the Norwegian Parliament decided to establish a new firing range in a less vulnerable area and that military activities should be phased out in 2005–2008. The ultimate goal is to restore the areas used for military activities to a near-natural condition and include them in a larger complex of conservation areas in the Dovre Mountains.

The restoration of the firing range is by far the largest, most complex, and costly ecological restoration project initiated in Norway, and probably rivals any restoration project in mountain regions globally. The firing range covers 165 km^2 of high alpine terrain. Large technical firing facilities, including around 100 buildings and up to 90 km of roads, will be removed, and a number of large mass deposits reshaped to blend into the terrain. The total cost of the project is not yet known, but is likely to be at least EUR100 million. In phase 1, from 2006–2012, at a cost of approximately EUR40 million, most of the buildings and firing facilities will be removed. Restorative actions such as replanting and building up seed banks are already under way, partly building on a pilot project in 2002 when 2.2 km of road was removed and experiments with species and restoration techniques were undertaken. In phase 2, from 2013–2020, most of the roads will be removed. The cost of phase 2 has not yet been calculated.

The project is driven by an ambitious objective. It is intended to lead to increased conservation values, and land to be incorporated in the surrounding protected areas will be restored to as 'natural' a condition as possible. A project of this size and complexity raises a series of practical and scientific challenges. Large volumes of gravel, rocks and soil need to be relocated and fitted to the terrain. Vegetation needs to be grown from seed or transplanted from areas adjacent to roads and sites. Often, large plots need to be fertilised to establish plant cover within a reasonable time in an otherwise cold and harsh mountain environment. There are also challenges associated with human security, scientific approaches and public values. The firing range has been bombarded for 80 years and the entire area has to be searched and cleared manually of undetonated explosives before restoration. The roads transect a multitude of vegetation and terrain types, and different techniques have been used to construct them. Some stretches are homogenous, allowing the same restoration techniques for hundreds of metres; along other sections, techniques must be adapted to much shorter stretches. Furthermore, alpine environments have nutrient-poor soils and low temperatures, so regrowth is very slow. No exotic plants and seeds can be introduced, so all restoration must rely on indigenous species and processes.

Researchers are faced with interesting questions. 'Naturalness' has potentially very different meanings to scientists and other stakeholders such as recreational groups, the tourism industry, or local communities. Restoration ecologists need to identify what is scientifically feasible. How can one realistically, within the available budget and time frame, ensure a reasonable level of ecological functions; and what ecological condition is a relevant comparison? These evaluations must also be aligned with public perceptions of what constitutes 'naturalness' — a largely aesthetic issue. The goal of bringing the area back to more or less its 'original' condition also entails negotiation between interest groups about the baseline condition: does 'naturalness' exclude any signs of former human activities in an area that is partly seen as a cultural landscape by local communities; or can added conservation value be interpreted as increasing the future value for tourism and hence an argument for keeping some roads for better access? Ultimately, this project may contribute to an important discussion of what we call restored environments and how they are valued.

Source: Bjørn P. Kaltenborn (Norwegian Institute for Nature Research, Norway).

Photo: © Bjørn P. Kaltenborn (Norwegian Institute for Nature Research, Norway).
This sign in Dovre-Sunndalsfjella National Park contains information about the environmental history and attributes of the area as well as recreational opportunities. A major objective of the restoration is to open up the area for more public access and provide new recreational opportunities.

9.1 Natura 2000 sites

The issues addressed in this section are the relative proportions of Natura 2000 sites within and outside mountains at the level of massifs and at the national level, the habitat types within these sites, changes in land-cover classes in these sites, and overlaps with High Nature Value farmland. The analyses are based on data held by the EEA.

9.1.1 Distribution

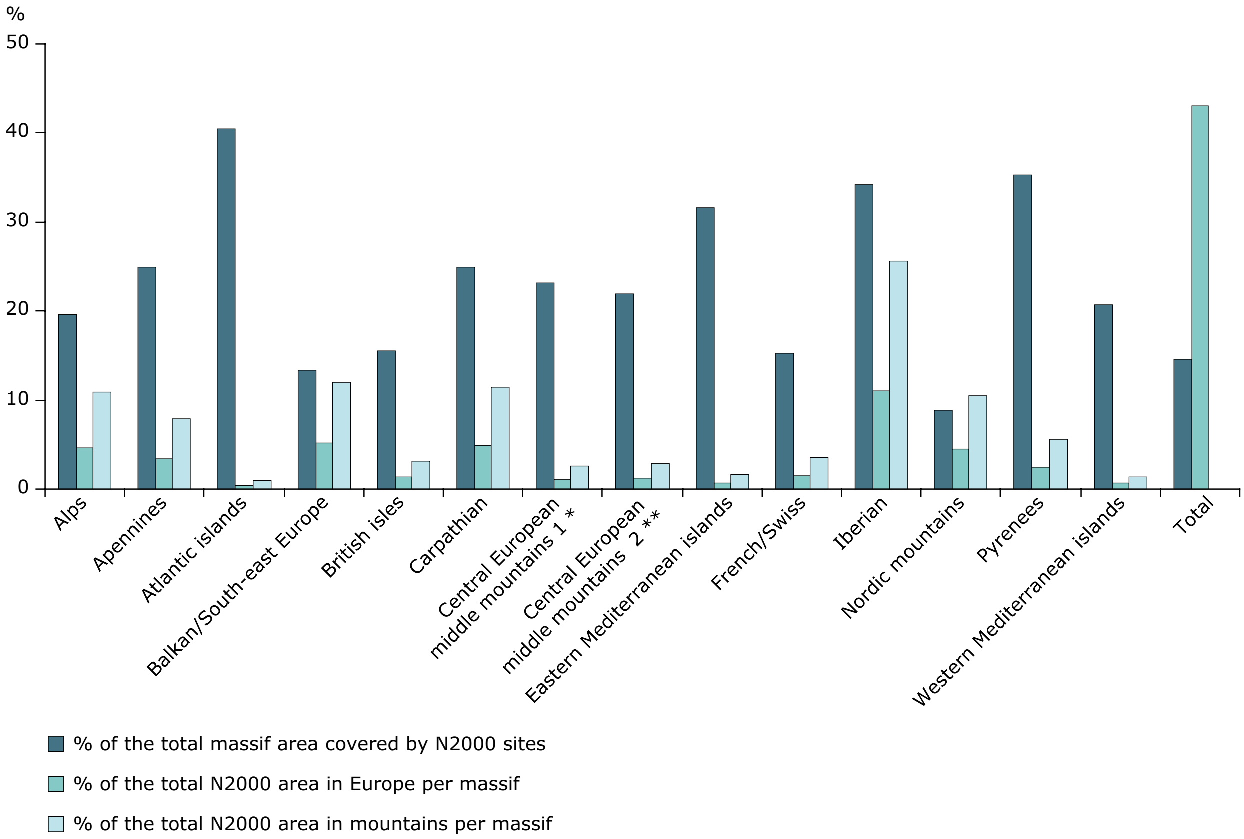
To characterise the distribution of Natura 2000 sites across the massifs, the following variables were analysed:

- percentage of the area of each massif covered by Natura 2000 sites;
- percentage of the total area covered by Natura 2000 sites in Europe per massif;
- percentage of the total area covered by Natura 2000 sites in mountains per massif.

The results are shown in Figure 9.1. From this, the following conclusions can be derived:

- of the total area occupied by Natura 2000 sites in the EU-27, 43 % is in mountain areas, a considerably greater proportion than the 29 % of the EU covered by mountain areas (Table 1.2);
- Natura 2000 sites cover 14.6 % of the mountain area of the EU-27;
- the proportion of the area within Natura 2000 sites in specific massifs varies considerably;
- the massifs with the highest proportion of their area within Natura 2000 sites are the Atlantic islands (41 %), the Pyrenees (35 %), the Iberian mountains (34 %) and the eastern Mediterranean islands (32 %);
- the massifs with the lowest proportion of their area within Natura 2000 sites all include considerable proportions of their area within non-EU Member States: the Nordic mountains (9 %) which include the non-EU Member States of Iceland and Norway; Balkans/South-east Europe (13 %), which include many non-EU Member States; the French/Swiss middle mountains (15 %), which include a considerable area in Switzerland;
- among massifs that are predominantly within EU Member States, the massif with the lowest

Figure 9.1 Distribution of the area of Natura 2000 sites in mountain massifs



Note: * = Belgium and Germany; ** = the Czech Republic, Austria and Germany.

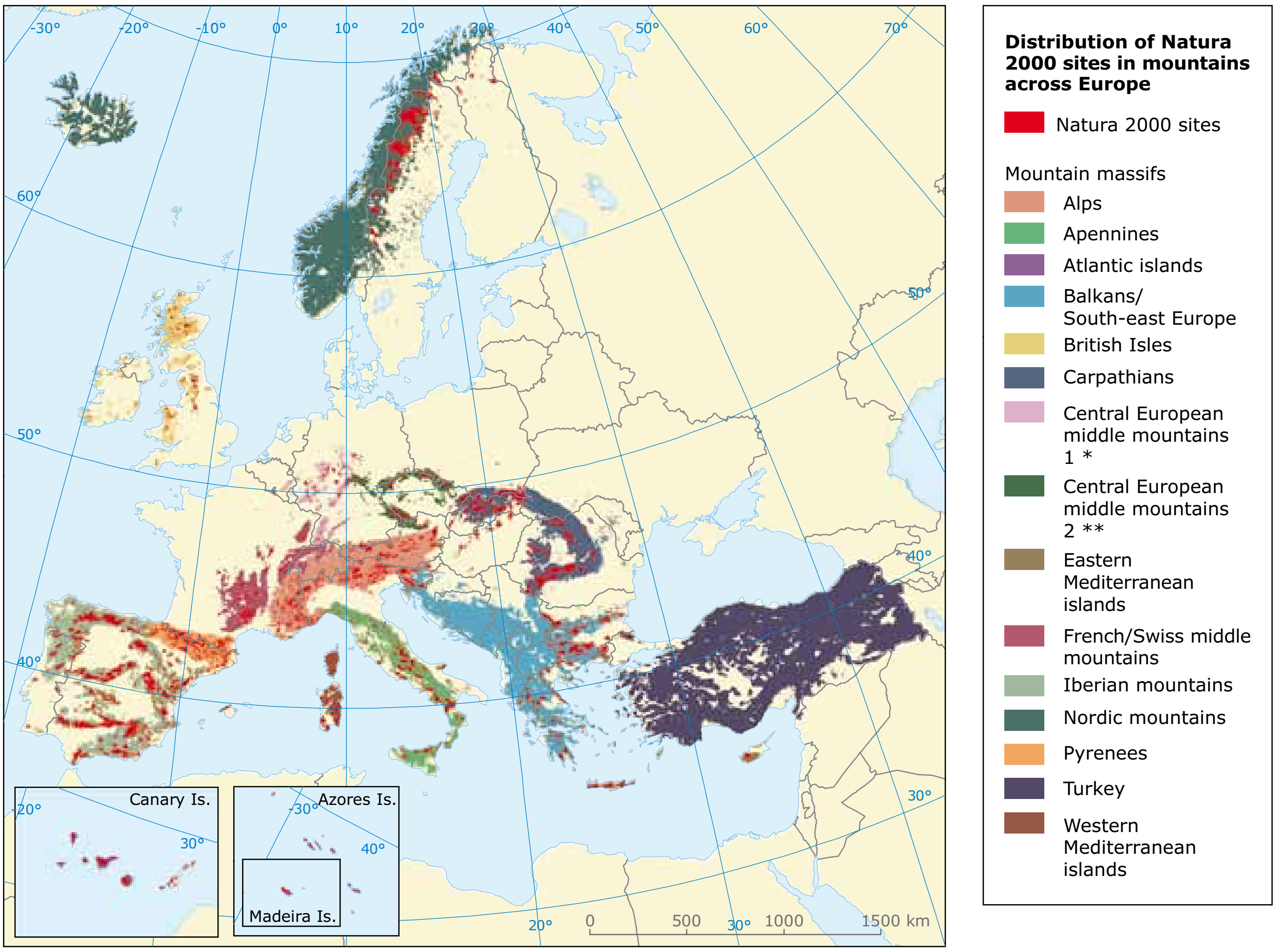
proportion of its area in Natura 2000 sites is the British Isles (16 %);
- of all the massifs in the EU-27 the Iberian mountains have the highest proportion of their area within Natura 2000 sites.

Map 9.1 shows the distribution of Natura 2000 sites in mountains across Europe, and Table 9.1 shows the area of Natura 2000 sites in mountains for each EU-27 Member State and massif. Considering the larger massifs and specific countries, the following conclusions may be noted with regard to high proportions of area within Natura 2000 sites:

- the massifs with the highest proportion of their area within Natura 2000 sites are on the Iberian Peninsula: the Iberian mountains (34 %) and the Pyrenees (35 %); these are mainly in Spain, which has 19 % of its national area within these sites — it should also be noted that, overall, Spain has the third highest proportion of its national area in Natura 2000 sites (26 %);
- Slovenia has the largest proportion (29 %) of its mountain area within Natura 2000 sites, with slightly more in the Alps than the Balkans/South-east Europe massif; overall, it should also be noted that Slovenia has the highest proportion of its national area in Natura 2000 sites (36 %);
- Slovakia has the second highest proportion (23 %) of its mountain area within Natura 2000 sites; again, this is a country with a high proportion of its national area in Natura 2000 sites (29 %);
- Bulgaria also has a high proportion (19 %) of its mountain area within Natura 2000 sites; this is another country with a high proportion of its national area in Natura 2000 sites (29 %).

Thus, for all four countries, a high area of Natura 2000 sites within mountains is closely linked to the fact that these countries have a significant proportion of their national area within Natura 2000 sites.

Map 9.1 Distribution of Natura 2000 sites in mountains across Europe



Note: * = Belgium and Germany; ** = the Czech Republic, Austria and Germany.

Table 9.1 Area of Natura 2000 (N2000) sites within mountains for each EU-27 Member State and massif (km²)

	Area of Natura 2000 (% of the country area)	Alps	Apennines	Atlantic islands	Balkans/South-east Europe	British Isles	Carpathian mountains	Central European middle mountains 1 *	Central European middle mountains 2 **	Eastern Mediterranean islands	French/ Swiss middle mountains	Iberian mountains	Nordic mountains	Pyrenees	Western Mediterranean islands	Area Natura 2000 mountain (% of country area)
Austria	12 307 (15 %)	8 497														9 529 (11 %)
Belgium	3 900 (13 %)							286			19					305 (1 %)
Bulgaria	31 927 (29 %)				21 254											21 254 (19 %)
Cyprus	1 003 (11 %)									950						950 (10 %)
Czech Republic	10 532 (13 %)						1 647		5 827							7 474 (9 %)
Denmark	3 863 (9 %)															0 (0 %)
Estonia	7 921 (17 %)															0 (0 %)
Finland	48 791 (14 %)												4 285			4 285 (1 %)
France	68 170 (12 %)	9 723						11			12 492			6 512	1 138	29 876 (5 %)
Germany	48 882 (14 %)	2 107						8 522	1 637		0.2					12 266 (3 %)
Greece	25 056 (19 %)				16 062					4 538						20 600 (16 %)
Hungary	19 916 (21 %)	90			192		3 161									3 443 (4 %)
Ireland	4 484 (6 %)					1 861										1 861 (3 %)
Italy	57 337 (19 %)	14 920	27 890		67										3 387	46 264 (15 %)
Latvia	7 135 (11 %)															0 (0 %)
Lithuania	7 373 (11 %)															0 (0 %)
Luxembourg	456 (18 %)							49								49 (2 %)
Malta	38 (12 %)														16	16 (5 %)
Netherlands	5 785 (15 %)															0 (0 %)
Poland	51 703 (17 %)						4 931		1 488							6 419 (2 %)
Portugal	18 861 (20 %)			534								8 275				8 809 (10 %)
Romania	30 903 (13 %)				1 053		19 155									20 208 (8 %)
Slovakia	14 116 (29 %)						11 162									11 162 (23 %)
Slovenia	7 203 (36 %)	2 605			3 343											5 948 (29 %)
Spain	133 662 (26 %)			2 780								81 571		12 939	455	97 745 (19 %)
Sweden	56 406 (13 %)												32 425			32 425 (7 %)
United Kingdom	17 013 (7 %)					9 338						2				9 340 (4 %)
Total		37 942 (20 %)	27 890 (25 %)	3 314 (41 %)	41 971 (13 %)	11 199 (16 %)	40 056 (25 %)	8 868 (23 %)	9 984 (22 %)	5 488 (32 %)	12 511 (15 %)	89 848 (34 %)	36 710 (9 %)	19 451 (35 %)	4 996 (21 %)	

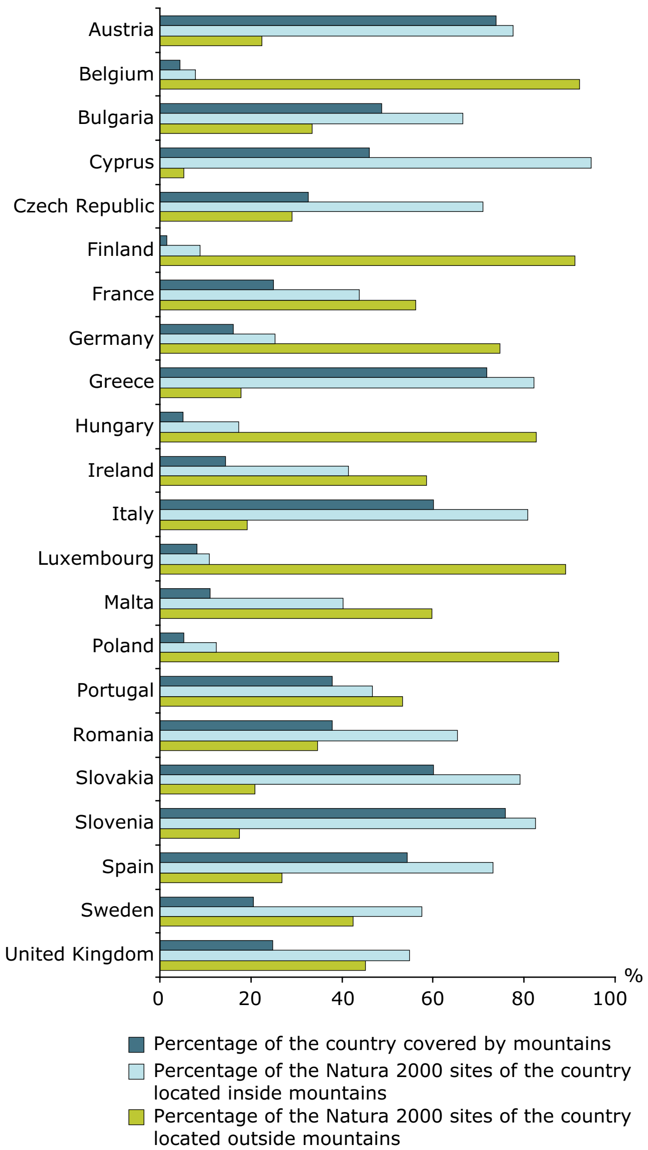
Note: * = Belgium and Germany; ** = the Czech Republic, Austria and Germany.
The last row gives the surface area and percentage for each massif. The last column gives the surface area and percentage for each EU-27 Member State. Empty cells mean 0 km².

In terms of proportion of national mountain area within Natura 2000 sites, the next highest ranking countries are Greece (16 %) and Italy (15 %); these proportions are similar to the national proportion (19 %) of their territory in Natura 2000 sites.

9.1.2 Relative area of Natura 2000 sites within and outside mountains

In order to assess the representation of Natura 2000 sites inside mountain massifs, Figure 9.2 compares the percentage of sites located inside and outside mountains for each country, as well as the proportion of the national area covered by mountains (Table 1.2).

Figure 9.2 National percentage of area covered by Natura 2000 sites inside and outside mountains by country, and of area covered by mountains



From Figure 9.2, it is clear that the proportion of the total area of Natura 2000 sites in mountains is very high in a number of countries: Cyprus (95 %), Slovenia (83 %), Greece (82 %), Italy (81 %), Slovakia (79 %), Austria (78 %), Spain (73 %) and Czech Republic (71 %). Only five countries have less than 20 % of the total area of Natura 2000 in mountains: Belgium (8 %), Finland (9 %), Luxembourg (11 %), Poland (12 %) and Hungary (17 %). For the majority of the first group (apart from Cyprus), mountains cover at least half of their national area, from 54 % in Spain to 74 % in Austria. Conversely, for all of the second group, mountains cover less than 10 % of their national area. To provide a further basis for comparison, a ratio relating the percentage of the national area covered by mountains to the percentage of the area of Natura 2000 sites located inside mountains was computed. Countries with a ratio < 1.5 (i.e. the percentage of Natura 2000 sites located inside mountains is less than 50 % larger than the percentage of mountain coverage) were regarded as having a good proportion of Natura 2000 sites in mountainous areas. These countries were Austria, Bulgaria, Greece, Italy, Luxembourg, Portugal, Slovakia, Slovenia and Spain. Most of these countries are those that have mountains covering at least half their national area, with the exception of Luxembourg (8 %), Portugal (38 %) and Bulgaria (49 %). Countries with a ratio > 1.5 (i.e. the percentage of Natura 2000 sites located inside mountains is more than 50 % larger than the percentage of mountain coverage) were regarded as having an over-representation of Natura 2000 sites in mountainous areas. These countries were Belgium, Cyprus, the Czech Republic, Finland, France, Germany, Hungary, Ireland, Malta, Poland, Romania, Sweden and the United Kingdom. In none of these countries do mountains cover more than half of their area; the highest proportions are in Cyprus (46 %), Romania (38 %), and the Czech Republic (33 %). Finally, in every country with mountains, the proportion of the area within Natura 2000 sites was greater than the proportion of the area covered by mountains; the smallest ratios were 1.05 (Austria) and 1.14 (Greece). Overall, these figures show the relative importance of the habitat types of mountain areas across the European Union with regard to the conservation of biodiversity, whatever the proportion of the national area within mountains.

9.1.3 Habitat types

To gain a deeper understanding of the habitat types represented within Natura 2000 sites across the mountains of the EU, an analysis was made of the relative area of Annex I habitat types within each Natura 2000 site. The available data only record the presence and area of a particular habitat within each site, but not the geographical location of the area of the habitat; thus it was not possible to make a comparative spatial analysis of the area covered by each habitat type across Natura 2000 sites. Table 9.2 shows the total number of Annex I habitats and the total number of different habitat types for each massif. The list of habitat types is available in Appendix 2. This is therefore an analysis of the frequency with which a habitat type occurs, not its relative area. From this information, it is possible to gain some insight into the distribution of each habitat type. The last row of Table 9.2 shows the number of Annex I habitat types for each massif. This information shows that the Iberian mountains, Balkans/South-east Europe, Alps, Apennines, Pyrenees and western Mediterranean islands massifs contain almost every habitat type (27–30 out of 33 types), while the central European, Nordic, Atlantic islands and Carpathian massifs have the fewest habitat types (16–19 types).

Figures 9.3 to 9.9 illustrate the relative distribution of a number of habitat types across the massifs. Eight habitat types are found in every massif. Some of these are particularly linked to mountains, such as the rocky habitats and caves (habitat types 81, 82, 83) shown in Figure 9.3. These are predominantly found in the Alps (21 %), the central European middle mountains 1 and 2 (16 %) and the Iberian mountains (13 %) and are also the most frequent habitat type in the Natura 2000 sites of the Atlantic islands. As noted in Chapter 7, forests are the predominant land cover in most European massifs, and the 'forests of temperate Europe' habitat type (91) is also found in all massifs. Figure 9.4 shows that this is most frequently found in the Alps (20 %) and the central European middle mountains 2 (18 %). This is the most frequent habitat type in the Natura 2000 sites of seven massifs. The two habitat types specifically named as 'mountainous' are also both forest, but are limited in their distribution. 'Temperate mountainous coniferous forests' (94) are found predominantly in the Alps (54 %), as well as in the Carpathians (13 %) and central European middle mountains 2 (12 %) (Figure 9.5). 'Mediterranean and Macaronesian mountainous coniferous forests' (95) are more evenly distributed, with 30 % in the Iberian mountains and 10–16 % in the Alps, Apennines, Atlantic islands, Balkans/South-east Europe, and the Pyrenees (Figure 9.6). 'Mediterranean deciduous forests' (92) are the most frequent habitat type in mountain Natura 2000 sites in the Iberian mountains. 'Forests of boreal Europe' (90) are only found in the Nordic mountains, where they are the most frequent habitat type in Natura 2000 sites.

With regard to lower stature habitat types, 'temperate heath and scrub' (40) is found in all massifs, with the highest frequency in the Iberian mountains (24 %) and the Alps (18 %) (Figure 9.7). This is the most frequent habitat type in the British Isles, which have relatively little forested area. The high frequency of this habitat type contrasts with 'thermo-Mediterranean and pre-steppe brush' (53), which is also predominantly found in the Iberian mountains (35 %) and the Apennines (31 %), but is confined to only eight massifs in the southern part of Europe (Figure 9.8). Another frequently occurring habitat type is 'semi-natural dry grasslands and scrubland facies' (62), which is the most frequent type in the Apennines (22 %), and is also found particularly in the Alps (16 %), Central European middle mountains 1 (14 %) and Iberian mountains (14 %) (Figure 9.9).

9.1.4 Changes in land use

As noted in Section 8.1.3, one of the principal aims of the Habitats Directive is to maintain habitats within Natura 2000 sites in favourable conservation status. An analysis of specific changes between types of land use can therefore be useful in assessing the effects of designation and the impacts on this status. Tables 9.3 and 9.4 show data for 1990 and 2000 for four land-cover classes (see Section 7.2) between which changes in land use might have particular impacts on conservation status:

- 1: Artificial surfaces;
- 2A: Arable land and permanent crops;
- 2B: Pastures and mosaic farmland;
- 3A1: Standing forests.

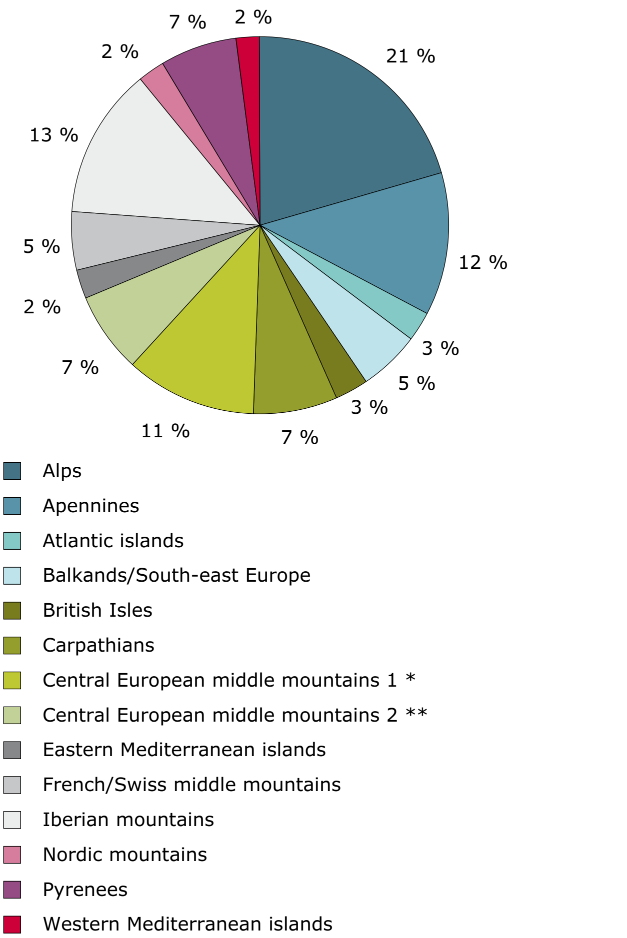
While these tables show the distribution of the different land-cover groups in all massifs for 1990 and 2000, it should be noted that not all the area of each massif is taken into account because no land-cover data are available for some parts of certain massifs. Particularly significant among these data gaps are the lack of 1990 and 2000 data for Switzerland (Alps, French/Swiss middle mountains), the islands of Portugal (Atlantic islands), Iceland and Norway (Nordic mountains). In addition, no data were available for 1990 for Finland and Sweden (Nordic mountains), the United Kingdom (British Isles) or for Albania, Bosnia and Herzegovina, and the former Yugoslav Republic of Macedonia (Balkans/South-east Europe).

Table 9.2 Total number of Annex I habitat types per massif

Habitat types	Alps	Apennines	Atlantic islands	Balkans/ South-east Europe	British Isles	Carpathian mountains	Central European middle mountains 1 *	Central European middle mountains2 **	Eastern Mediterranean islands	French/Swiss middle mountains.	Iberian mountains	Nordic mountains	Pyrenees	Western Mediterranean islands
11	13	69	23	38	41				47	3	73		14	54
12	12	83	70	29	38				46	2	68	1	10	68
13	4	21		13	26	7	5	2	14	6	69		9	10
14	1	34	11	23	5				18		136		19	29
15	2	8		5		7					126		18	12
16												1		
21		17	10	27	25				33	2	47		4	29
22	3	28		11	1				18		28		3	43
23	2			1			4			3	2			
31	320	205	11	60	89	58	178	119	23	94	264	125	73	40
32	373	232	7	99	22	99	352	179	55	115	248	130	134	15
40	424	182	94	79	155	143	157	99	9	112	547	98	169	34
51	85	229		23	25	59	141	27		102	102		96	8
52	59	132		58					35	15	311		69	59
53	15	262	113	11					40		295		7	101
54	3	32		37					80		2		3	30
61	440	183	11	60	55	159	128	70		60	271	65	103	6
62	584	797		157	83	264	493	242	37	185	509	32	182	57
63	8	64		1						3	146			19
64	606	265	15	89	50	212	445	247	14	155	399	43	143	24
65	450	103		60	7	253	526	281		138	128	35	104	
71	328	37	9	14	128	106	128	146		111	117	154	51	1
72	434	129	13	39	80	139	146	61	1	67	148	70	92	14
73												103		
81	427	169		49	48	113	201	120	25	81	169	52	105	9
82	536	432	33	145	83	186	306	218	61	140	456	65	180	59
83	231	100	119	106	26	123	136	69	47	65	139	14	101	40
90												295		
91	738	355	4	215	134	436	704	373	5	237	381	121	205	13
92	166	662	21	141		11			72	23	624		155	62
93	71	433	105	55					71	22	492		143	110
94	388	5		19		97	31	91		20	3		76	
95	84	129	95	79		2			46	5	234		78	31
Total	**29**	**29**	**18**	**30**	**20**	**19**	**17**	**16**	**22**	**25**	**30**	**17**	**28**	**27**

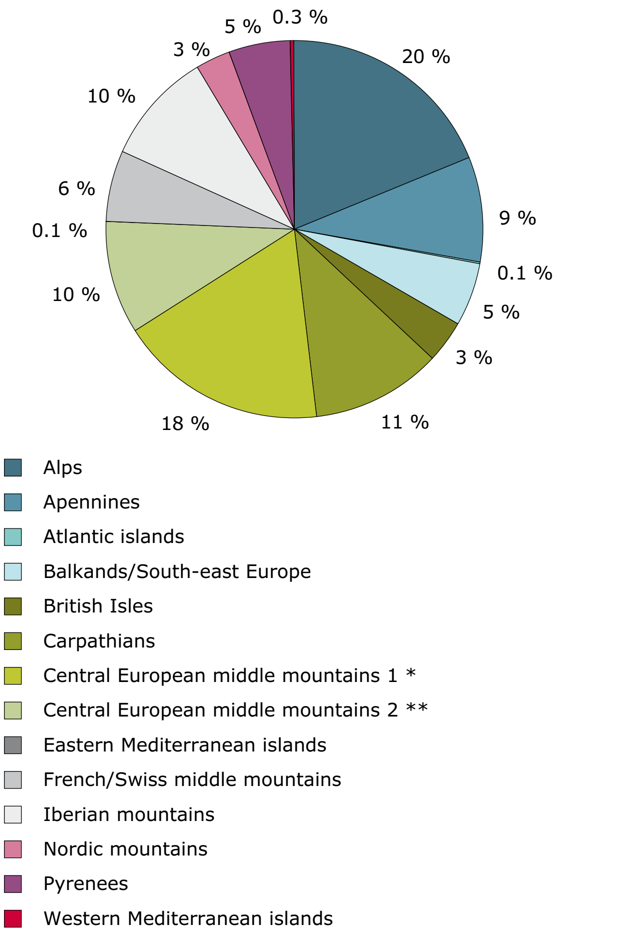
Note: * = Belgium and Germany; ** = the Czech Republic, Austria and Germany.
The last row gives the total number of different Annex I habitat types present in the massif. Empty cells indicate the absence of the habitat type in the massif. The habitat type description corresponding to the habitat code can be found in Appendix 2.

Figure 9.3 Distribution of the 'rocky habitats and caves' (8 is an aggregation of 81, 82 and 83) Annex I Habitat across the massifs



Note: * = Belgium and Germany;
** = the Czech Republic, Austria and Germany.

Figure 9.4 Distribution of the 'forests of temperate Europe' (91) Annex I Habitat across the massifs



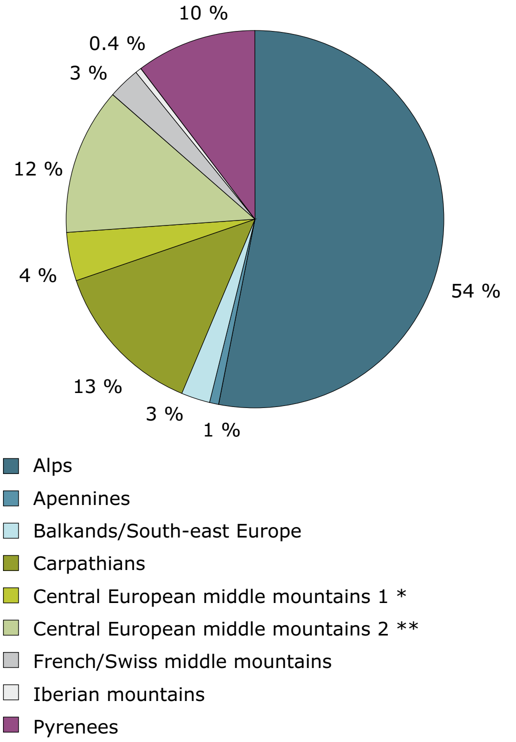
Note: * = Belgium and Germany;
** = the Czech Republic, Austria and Germany.

In both 1990 and 2000, the proportion of group 1 (artificial surfaces) is less than 1 % of the area of Natura 2000 sites within mountains in all the massifs except for central European mountains 2. Overall, this land-cover group is most frequent in the central European middle mountains 1, and in all massifs the proportion is significantly less within Natura 2000 sites than outside them.

Classes 2A (arable land and permanent crops) and 2B (pastures and mosaic farmland) are also more frequent outside Natura 2000 sites than inside them. The proportions of 2A are particularly high in the Apennines, with 10.8 % of the area of Natura 2000 sites in both 1990 and 2000 (and 32.2 % outside, the second highest proportion after the Atlantic islands, 35.8 %). Particularly high proportions are also found in the Natura 2000 sites of the central European middle mountains 2 (7.5 % in 2000) and the Iberian mountains (6.9 % in 2000). The lowest proportions are in the Nordic mountains, British Isles and Alps, both within and outside Natura 2000 sites.

Class 2B is most frequent in the Natura 2000 sites of the French/Swiss middle mountains (France only: 22.9 % in 2000), where the highest proportion outside Natura 2000 sites (39.1 %) is also found. High proportions are also found in the Natura 2000 sites of the central European middle mountains 1 and 2 (15.9 % and 17.9 %, respectively, in 2000). Again, the lowest proportions in Natura 2000 sites are in the Nordic mountains and the British Isles;

Figure 9.5 Distribution of the 'temperate mountainous coniferous forests' (94) Annex I Habitat across the massifs



Note: * = Belgium and Germany;
** = the Czech Republic, Austria and Germany.

Figure 9.6 Distribution of the 'Mediterranean and Macaronesian mountainous coniferous forests' (95) Annex I Habitat across the massifs

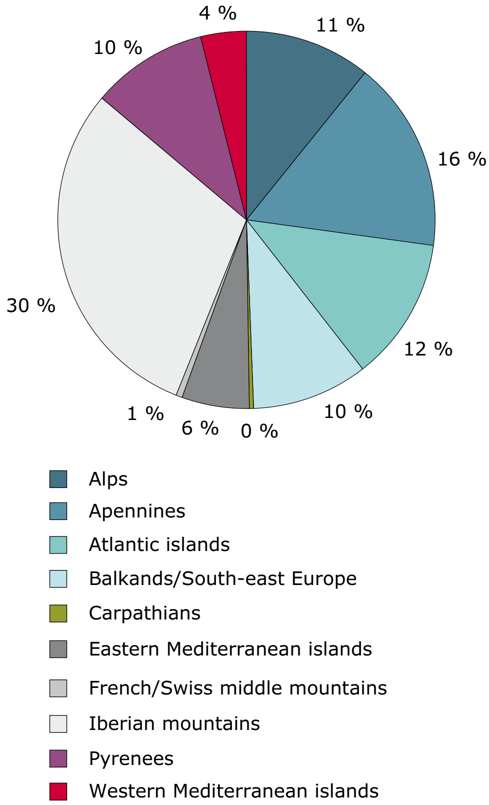
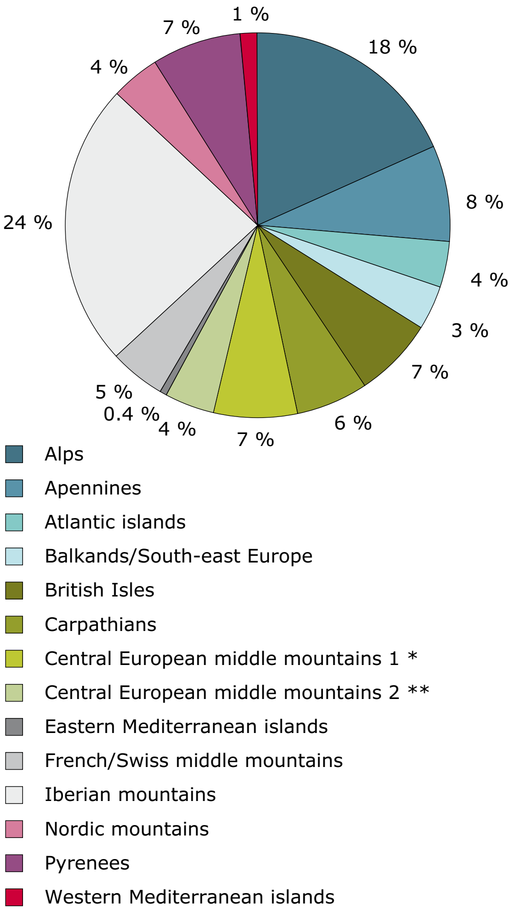


Table 9.3 Distribution of the land-cover classes within and outside Natura 2000 sites in each mountain massif in 1990 (% of total massif area, excluding surface without data)

Massif	Land cover classes 1990							
	1		2A		2B		3A1	
	Inside N2000	Outside N2000	Inside N2000	Outside N2000	Inside N2000	Outside N2000	Inside N2000	Outside N2000
Alps	0.41	3.38	1.13	4.05	4.93	17.46	40.75	51.03
Apennines	0.48	2.42	10.84	32.35	8.60	19.03	50.69	33.47
Atlantic islands	0.18	4.86	3.98	35.79	2.35	7.14	27.84	4.55
Balkans/South-east Europe	0.62	1.69	3.43	8.01	10.26	21.64	53.52	39.92
British Isles	0.01	0.25	0.00	0.68	2.52	27.90	3.10	11.62
Carpathian mountains	0.88	5.24	2.74	12.69	10.14	25.45	74.48	50.49
Central European middle mountains 1 *	0.58	6.27	4.83	15.77	15.75	22.64	75.07	54.10
Central European middle mountains 2 **	1.20	4.79	10.88	25.05	14.61	24.25	61.27	43.39
Eastern Mediterranean islands	0.18	0.97	4.33	20.83	9.41	21.74	10.35	5.54
French/Swiss middle mountains	0.67	2.86	3.24	6.01	22.91	39.15	52.40	44.20
Iberian mountains	0.16	0.79	6.91	22.77	10.23	22.03	32.89	20.01
Nordic mountains	No data	No data	No data	No data	No data	No data	No data	No data
Pyrenees	0.20	1.59	1.95	12.91	4.51	17.45	47.46	40.66
Western Mediterranean islands	0.26	1.35	3.60	9.63	5.90	17.54	29.43	26.13
Total	**0.45**	**2.58**	**4.95**	**14.47**	**9.67**	**22.35**	**47.17**	**38.11**

Note: * = Belgium and Germany; ** = the Czech Republic, Austria and Germany.

Figure 9.7 Distribution of the 'temperate heath and scrub' (40) Annex I Habitat across the massifs



Note: * = Belgium and Germany;
** = the Czech Republic, Austria and Germany.

Figure 9.8 Distribution of the 'thermo-Mediterranean and pre-steppe brush' (53) Annex I Habitat across the massifs

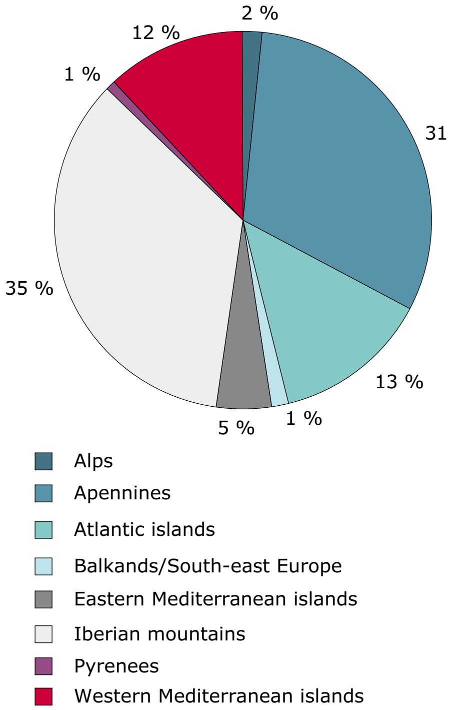
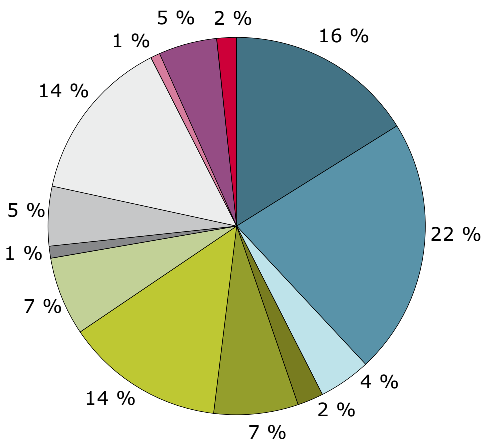


Table 9.4 Distribution of land-cover classes within and outside Natura 2000 sites in each mountain massif in 2000 (% of total massif area, excluding surface without data)

Massif	Land cover classes 2000							
	1		2A		2B		3A1	
	Inside N2000	Outside N2000	Inside N2000	Outside N2000	Inside N2000	Outside N2000	Inside N2000	Outside N2000
Alps	0.42	3.51	1.13	4.03	4.91	17.35	41.09	51.38
Apennines	0.50	2.58	10.84	32.21	8.54	18.86	50.91	33.75
Atlantic islands	0.18	5.37	4.02	35.81	2.35	7.12	27.78	4.54
Balkans/South-east Europe	0.64	1.51	3.45	6.48	10.26	22.36	53.57	40.44
British Isles	0.05	0.87	0.03	0.73	3.85	18.60	3.14	13.59
Carpathian mountains	0.88	5.26	2.62	12.46	10.11	25.54	74.64	50.34
Central European middle mountains 1 *	0.61	6.62	4.62	15.39	15.93	22.69	74.93	53.84
Central European middle mountains 2 **	1.21	4.93	7.53	21.11	17.91	28.01	60.76	43.79
Eastern Mediterranean islands	0.34	1.68	4.13	20.38	8.14	20.71	21.19	9.64
French/Swiss middle mountains	0.69	2.95	3.26	6.02	22.92	39.11	52.56	44.13
Iberian mountains	0.21	1.05	6.93	22.76	10.30	22.20	33.23	19.88
Nordic mountains	0.02	0.21	0.01	0.32	0.03	0.33	34.53	43.67
Pyrenees	0.24	1.76	1.94	12.88	4.48	17.30	47.49	39.72
Western Mediterranean islands	0.31	1.62	3.47	9.17	5.67	16.61	29.25	26.12
Total	**0.42**	**2.36**	**4.19**	**11.91**	**8.59**	**21.03**	**44.89**	**37.48**

Note: * = Belgium and Germany; ** = the Czech Republic, Austria and Germany.

Figure 9.9 Distribution of the 'semi-natural dry grasslands and scrubland facies' (62) Annex I Habitat across the massifs



- Alps
- Apennines
- Balkands/South-east Europe
- British Isles
- Carpathians
- Central European middle mountains 1 *
- Central European middle mountains 2 **
- Eastern Mediterranean islands
- French/Swiss middle mountains
- Iberian mountains
- Nordic mountains
- Pyrenees
- Western Mediterranean islands

Note: * = Belgium and Germany;
** = the Czech Republic, Austria and Germany.

though in the latter the proportion outside Natura 2000 sites is quite high (18.6 % in 2000).

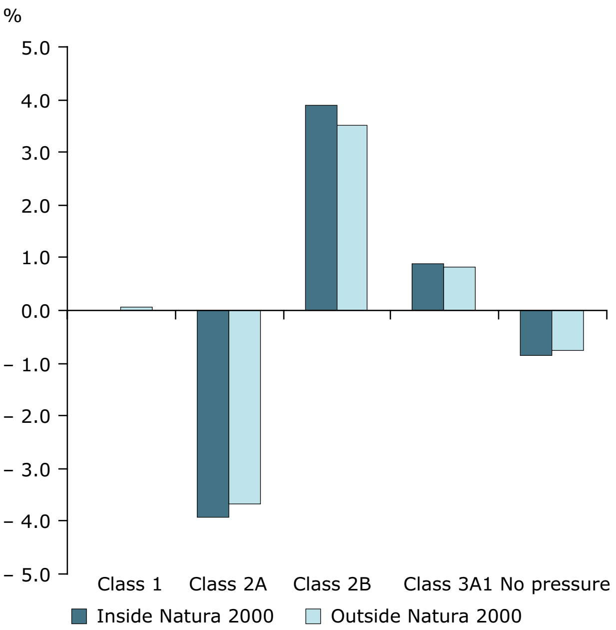
As might be expected from the findings on land cover (Section 7.2) and habitat types (Section 9.1.3), class 3A1 (standing forests) was the dominant land-cover group in mountains, covering 44.9 % of the total area of Natura 2000 sites in mountains and 37.5 % outside these sites. The highest proportions are in the Natura 2000 sites of central and south-eastern Europe, with values over 50 % also in sites in the French/Swiss middle mountains and the Apennines. However, this group is poorly represented in the British Isles (3.1 % in Natura 2000 sites in 2000), which also has the lowest proportion outside these sites after the massifs of the eastern Mediterranean islands. While the proportion of this land-cover group is generally higher within Natura 2000 sites than outside them, this was not true for the Nordic mountains (inside 34.5 %, outside 43.7 %) which are largely forested; the Alps (inside 41.1 %, outside 51.4 %); or the British Isles (inside 3.1 %, outside 13.6 %) where a large proportion of the forests were planted in the 20th century.

An analysis of changes in land cover between 1990 and 2000 was done for two countries that were covered in both CLC1990 and CLC2000: the Czech Republic and Germany (Figures 9.10 and 9.11). As noted in Section 7.3.1, the changes in the Czech Republic from 1990 to 2000 were greater than in any other EU Member State and were particularly in the category of 'agricultural internal land conversion'. The changes inside and outside Natura 2000 areas showed similar directions, with the largest changes in agricultural land, i.e. a 4 % decrease in arable land and permanent crops (class 2A) and a 4 % increase in pastures and mosaic farmland (class 2B). Overall, changes in Germany were much smaller. However, degrees of change were markedly different inside and outside Natura 2000 sites for artificial surfaces (class 1), which decreased in Natura 2000 sites, but increased outside them; and for pastures and mosaic farmland (class 2B), where the rate of increase in Natura 2000 sites was more than twice that outside them. A general conclusion is that the changes observed in 10 years are quite small, and that analysis over a longer time period — as represented, for instance for Slovakia's biosphere reserves in Box 9.3 — and in more detail (for example, Mücher *et al.*, 2006) is needed to assess trends and evaluate the effect of policies.

9.1.5 Overlaps between Natura 2000 and High Nature Value farmland

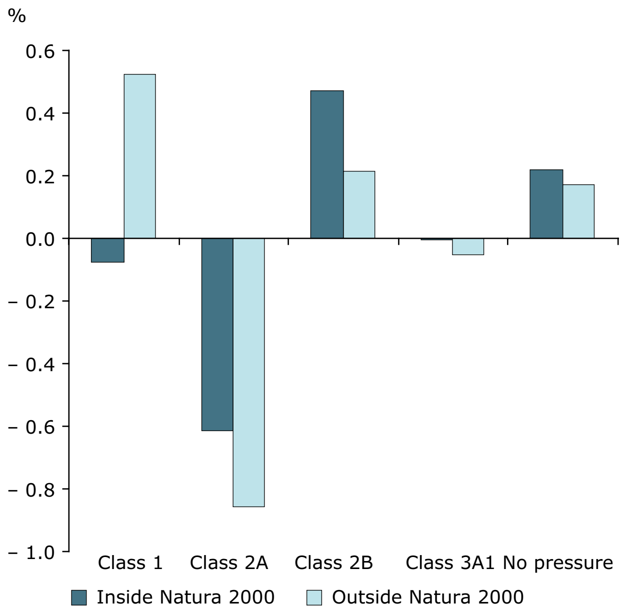
As noted in Section 7.4.2, High Nature Value (HNV) farmland covers 17 % of the area of the mountains of the EU-27 as a whole, and 33 % if the mountains of Finland and Sweden, where there is very little arable or pasture land, are excluded. It should also be noted that the presence of Natura 2000 sites is one of the criteria for designating HNV farmland. Nevertheless, considering that different policies often apply to these two designations, one deriving from EU legislation (Natura 2000 sites) and the other relating to modes of agricultural production through the Rural Development Programme (HNV farmland) , a comparison of the areas covered by the two designations may be useful to inform policy development and implementation (EEA, 2004). The assessment of overlaps between Natura 2000 sites and HNV farmlands per massif is summarised in Table 9.5. As HNV data refer only to EU Member States, only the areas covered by these data were considered when calculating the percentages shown.

Figure 9.10 Changes in land covers inside and outside Natura 2000 sites in the Czech Republic from 1990 to 2000



Note: 'No pressure' groups all land-cover classes except for the four shown, as these were judged to have little influence on biodiversity.

Figure 9.11 Changes in land covers inside and outside Natura 2000 sites in Germany from 1990 to 2000



Note: 'No pressure' groups all land-cover classes except for the four shown, as these were judged to have little influence on biodiversity.

For the mountains of the EU-27 as a whole, the proportion of the area covered by HNV farmland is greater than that covered by Natura 2000 sites. However, at the level of massifs, the difference in proportion varies considerably. In three massifs (central European middle mountains 1, Carpathians, Pyrenees), the area of Natura 2000 sites is greater than the area of HNV farmland. In two others (Apennines, central European middle mountains 2), it is similar. In all others, HNV covers a greater area than Natura 2000 sites; the greatest difference is in the British Isles. In terms of overlap between the two designations, although Natura 2000 data were used to produce the HNV dataset, so that the two datasets are correlated, the proportions of HNV farmland in any massif that is also with Natura 2000 sites are quite similar. The proportions are highest in the southern massifs of the Iberian mountains, the Pyrenees and the eastern Mediterranean islands, and lowest in the French/Swiss middle mountains (all in France).

The same data are presented at country level in Figure 9.12. This shows that the countries with the highest percentage of HNV farmland overlapped by Natura 2000 sites are those with less than 10 % of national areas within mountains, for instance Malta, Luxembourg and Finland. In a number of other countries, such as Slovakia, Portugal, Spain and Bulgaria, the proportion is over a third. There are only four countries where the proportion of HNV overlapped by Natura 2000 sites is greater outside mountains than inside them: Belgium, France, United Kingdom and Germany, in decreasing order of difference. If one considers that designation of HNV farmlands within Natura 2000 sites provide a greater level of habitat protection — which might be expected, because habitats within Natura 2000 sites should be maintained in a favourable conservation status — a low percentage of overlap may imply a potential risk of loss of HNV areas and thus a threat for biodiversity. From this point of view, HNV farmland in countries with a lower percentage of HNV farmland overlapped by Natura 2000 sites could be at greater risk; such as Cyprus and Belgium with a percentage below 10 %. All of these findings certainly relate to national differences in the designation of both HNV farmland and Natura 2000 sites, but may be used to inform future policy.

9.2 Nationally designated areas

As noted in the introduction to this chapter, all European states have designated protected areas — with a very wide range of objectives — under their own legislation. In some countries, protected areas

Box 9.3 Land use development and nature conservation problems in Slovak biosphere reserves

The aim of biosphere reserves (BRs) within UNESCO's Man and Biosphere programme is to reconcile biodiversity conservation, economic and social development and local cultural values through the sustainable use of landscapes and their resources (UNESCO, 2008). There are four BRs in Slovakia, all in mountain areas: Poľana; Tatry and Slovak Karst (both bilateral BRs, with Poland and Hungary respectively); and East Carpathians (a trilateral BR with Poland and Ukraine). The Slovak Karst and Tatry BRs extend from basin slopes up to karst plateaus (Slovak Karst) or periglacial high mountain landscapes (Tatry). Though their natural assets are different, their land-use development has been quite similar. The adjacent basins, settled in prehistoric and medieval times, were used mainly for crop production and grazing that strongly affected nearby forests. The areas of the Poľana and the East Carpathians BRs were colonised in the late 16th to 17th centuries, influencing the traditional land use, with smaller villages in narrow valleys with numerous forest pastures and subsistence based mainly on sheep and cattle grazing.

Until the first half of the 20th century, land use in all four BRs was quite stable and similar, based mainly on agriculture and forestry. Subsequently, urbanisation, agricultural collectivisation, and the development of industry and transport were predominantly in more suitable lowlands or basins where land use intensification prevailed. In higher and remote locations, extensification took place (Olah *et al.*, 2006). The few exceptions were in areas where land use was affected by new socioeconomic phenomena, such as the development of tourism centres in the Tatry BR, and the construction of dams and forced emigration in the East Carpathians BR (Map 9.2). The end of the 20th century and the first decade of this century were characterised by the rapid acceleration of land-use changes mainly because of socioeconomic changes, but also because of more frequent climate events.

Land use extensification, or even total abandonment, of these agricultural landscapes results from unprofitable management and changing social preferences. Most mountain grasslands are secondary vegetation formations whose continuity demands a certain amount of subsidiary energy through human activities. The economic regression of the 1990s, combined with negative demographic trends — emigration to larger towns and the rupture of peasants' links to their land due to 40 years of collectivised property — has led to land abandonment and secondary succession. Between 1949 and 2003, two-thirds of the grasslands in Poľana BR were overgrown (Gallayová, 2008). This natural process can lead to the loss of specialised species whose existence depends on specific management practices, as in the East Carpathians (Ružičková *et al.,* 2001). Decreases in biodiversity not only mean that the objectives of Natura 2000 are not achieved, but also cause significant loss of cultural landscapes, their scenery and traditional character (Olah and Boltižiar, 2009), especially in such extensively used sub-mountain and mountain cultural landscapes with HNV farmland. Land use intensification — either more intense management (forest monocultures or clearcutting) or urbanisation — also significantly alters or even completely destroys natural assets in protected areas. While forestry intensification affects almost all Slovak mountain BRs, the development of tourism centres and sport infrastructure mainly affects Tatry BR.

Relatively new phenomena affecting land use in the mountains of Slovakia are natural disasters: strong winds and heavy rain. These have caused wind destruction in forests, resulting in significant economic loss. While many consider these disasters to be a serious recent problem, analysis of historical maps shows that they have occurred several times in the same areas (Olah *et al.,* 2009). About 12 500 ha of forests were destroyed in Tatry BR after a wind storm in 2004, and are now a site of conflict between nature conservation (leaving part of the area to natural afforestation), forestry (fast clearing of the area and artificial reforestation), and tourism interests (using open space for new tourism infrastructure).

Source: Branislav Olah (EEA).

Photo: © Martin Boltižiar
Wind destruction area in the Tatry Biosphere Reserve, Slovakia.

Box 9.3 Land use development and nature conservation problems in Slovak biosphere reserves (cont.)

Map 9.2 Vanishing open landscape in the East Carpathians Biosphere Reserve, Slovakia

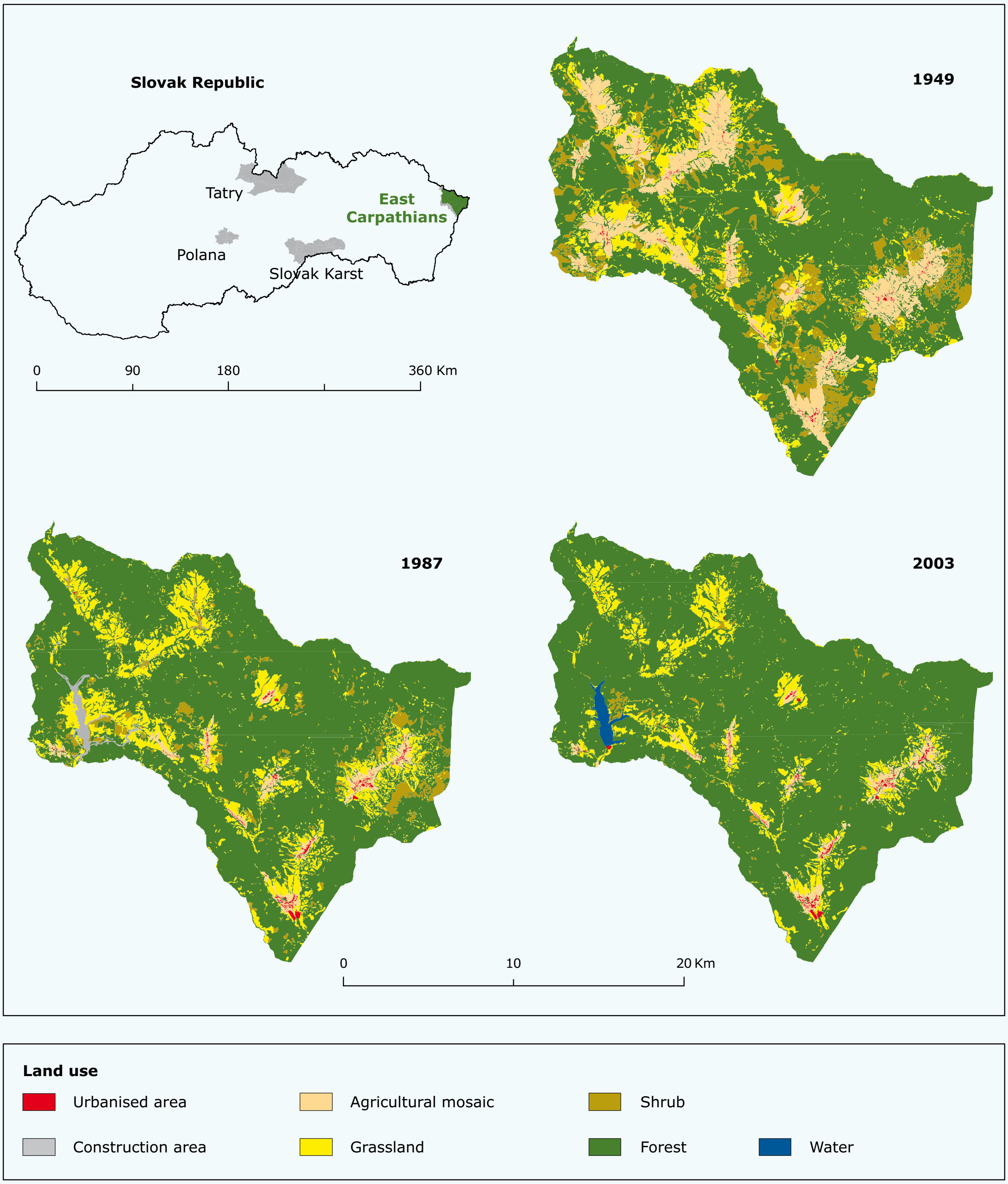


Table 9.5 Percentage overlap between HNV farmland and Natura 2000 sites in each massif

Massif	Coverage HNV farmland per massif		Coverage Natura 2000 per massif		% of HNV farmland overlapped by Natura 2000 per massif
	Km²	%	Km²	%	
Alps	41 655	24.9	37 997	19.7	21.7
Apennines	27 556	24.7	27 966	25.0	27.8
Atlantic islands	–	–	–	–	–
Balkans/South-east Europe	56 633	38.5	42 072	13.3	26.8
British Isles	40 211	56.8	11 249	15.5	22.2
Carpathians	29 631	21.4	40 123	24.9	20.9
Central European middle mountains 1 *	4 632	12.2	8 824	23.0	26.7
Central European middle mountains 2 **	9 444	20.8	9 928	21.9	23.3
Eastern Mediterranean islands	9 531	54.9	5 510	31.6	33.2
French/Swiss middle mountains	24 656	35.4	12 573	15.4	16.7
Iberian mountains	102 382	39.0	89 872	34.2	38.9
Nordic mountains	363	0.4	36 706	8.8	18.4
Pyrenees	16 379	30.0	19 400	35.2	35.6
Western Mediterranean islands	12 885	53.6	5011	20.8	20.2
Total (without Nordic mountains)	**375 595**	**34.3**	**310 525**	**23.3**	**26.2**

Note: * = Belgium and Germany; ** = the Czech Republic, Austria and Germany.
The Nordic mountains are not included in the average value in the last row because the HNV dataset includes only 23 % of the area of the massif, and the coverage is close to 0 %.

are also designated by sub-national authorities. The European inventory of these sites is held in the national module of the Common Database on Designated Areas (CDDA), maintained by the EEA and based on data submitted by national authorities — which may or may not include data relating to sub-national designations. This section presents the distribution of the nationally designated areas (NDAs) within massifs and countries, and compares the relative areas of NDAs both within and outside mountain areas in the EU-27, and also in relation to Natura 2000 sites.

9.2.1 Distribution

To characterise the distribution of NDAs across the massifs, the following variables were analysed:

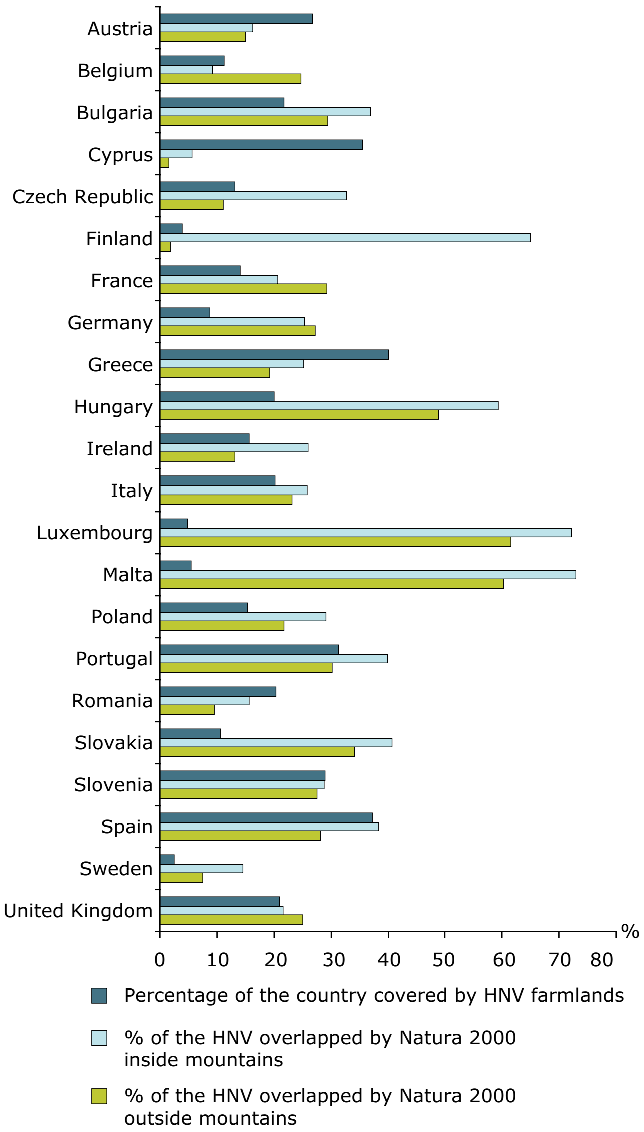
- percentage of the area of each massif covered by NDAs;
- percentage of the total area covered by NDAs in Europe per massif;
- percentage of the total area covered by NDAs in mountains per massif.

As the CDDA database does not include data for NDAs in the EU Member States of Ireland, Luxembourg and Poland, and the non-EU countries of Andorra, Albania, Bosnia and Herzegovina, the former Yugoslav Republic of Macedonia, Moldova and Ukraine, these countries are excluded from all analyses in this section.

The results are shown in Figure 9.13. From this, the following conclusions can be derived:

- Across Europe as a whole, 43.5 %
- of the total area of nationally designated areas is within mountain massifs;
- NDAs occupy 15.1 % of the total mountain area of Europe, a greater percentage than the global average of 11.4 % (Kollmair *et al.*, 2005);
- The proportion of the area within NDAs varies considerably between massifs;
- The middle mountains of central Europe (1: 74 %; 2: 40 %) have the highest proportions of their area in NDAs, far higher than the proportion in Natura 2000 sites (23, 22 % respectively);
- Four other massifs also have over a quarter of their area in NDAs: French/Swiss middle mountains (34 %); Atlantic islands (31 %, much lower than the relative area of Natura 2000 sites); eastern Mediterranean islands (26 %); British Isles (25 %);
- Only Turkey has less than 10 % of its mountain area in NDAs (2.6 %: Box 9.4) ;
- The Nordic mountains have the highest number of nationally designated areas at the European scale (10 %), followed by the Alps (5.6 %).

Figure 9.12 Percentage of HNV farmland overlapped by Natura 2000 sites inside and outside mountains at country level, and the mountain area of the country



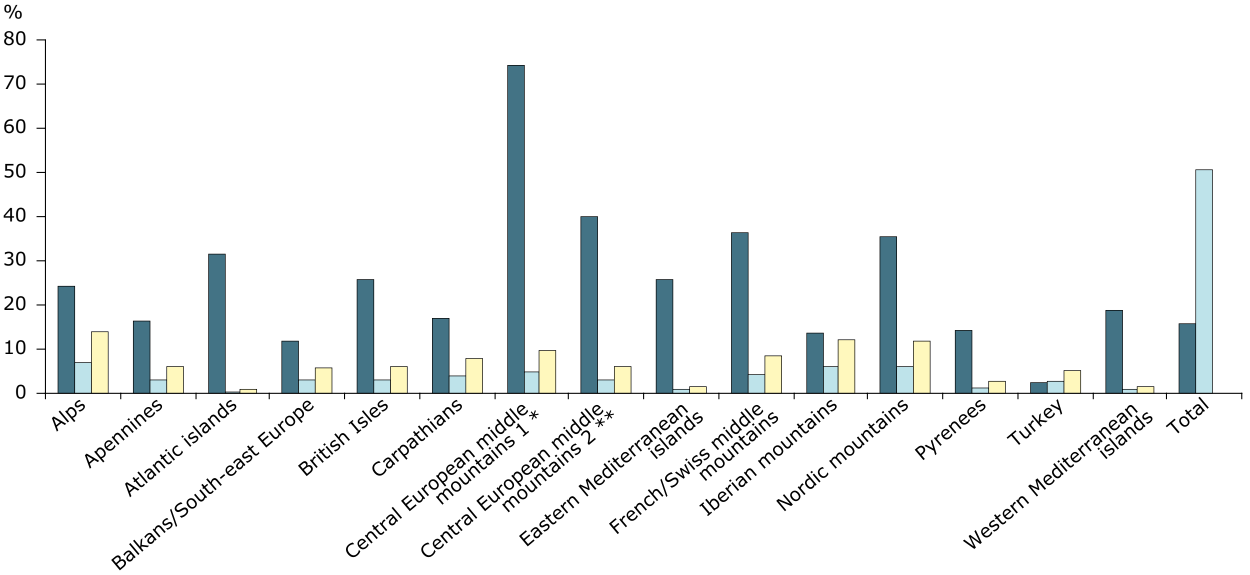
Map 9.3 shows the distribution of nationally designated areas in mountains across Europe for all countries for which data are available in the CDDA database (and can therefore be compared with Figure 9.4), and Tables 9.6 and 9.7 show the area of these sites per country and massif (compare Table 9.1). The following key conclusions may be drawn:

- the massifs with the highest proportion of their area in nationally designated areas are the relatively small central European middle mountains (1: 74 %; 2: 40 %) and the French/Swiss middle mountains (36 %); proportions that are far higher than those for Natura 2000 sites in these massifs;
- among the larger mountain massifs, the Alps have the largest proportion of their area in NDAs (24 %), including Austria's mountain area and France's mountain area; the proportion in EU Member States (24 %) is higher than for Natura 2000 sites (20 %);
- among the larger mountain massifs, the Nordic mountains rank second with respect to area within NDAs (20 %), including the mountain areas of Norway, Sweden, Iceland and Finland; in Island the proportion has recently been increased significantly by the designation of Vatnajökull National Park (Box 7.4);
- other large massifs have far less of their area in nationally designated areas; third and fourth in rank are the Carpathians (15 %, including mountain areas in Slovakia and Romania) and the Iberian mountains (14 %, including Spain's and Portugal's mountain areas); for both of these massifs, the proportion of the area within NDAs is significantly less than for Natura 2000 sites (25 % and 34 %, respectively);
- considering Europe as a whole, four countries account for nearly half of the total mountain area within nationally designated areas: France; Germany, Norway and Spain;
- after Finland, the countries with the highest proportion of their national mountain area in nationally designated areas are Hungary, another country with a small mountain area, and Lichtenstein, which is entirely mountainous;
- the countries with the next largest proportions of their mountain area in nationally designated areas are all countries with a considerable mountain area: Spain, Romania, Sweden, France, the United Kingdom and Austria).

9.2.2 *Relative area of nationally-designated areas within and outside mountains in the EU-27, and in relation to Natura 2000 sites*

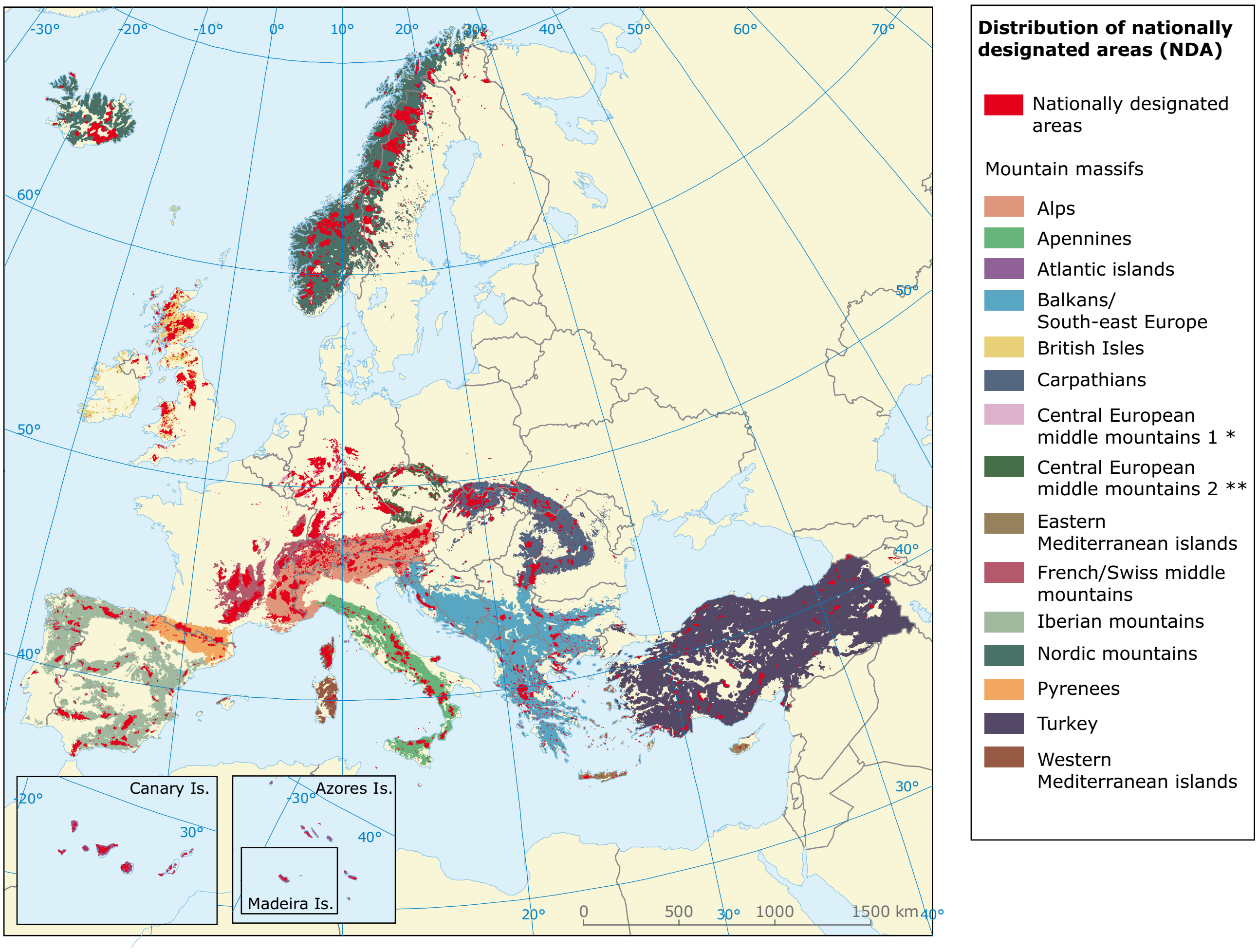
In order to assess the representation of NDAs inside mountain massifs within the EU-27, Figure 9.14 compares the percentage of sites located inside and outside mountains for each country, as well as the proportion of the national area covered by mountains (cf. Table 1.2). Unfortunately, no data were available for Ireland or Poland. Figure 9.14 shows that the proportion of the total area of NDAs in mountains is very high in a number of countries: Cyprus (93 %), Slovakia (91 %), Austria (89 %), Italy (87 %), Bulgaria (84 %), Greece (81 %), Spain (80 %) and Slovenia (73 %). These are the same mountainous countries with a similarly large proportion of their

Figure 9.13 Distribution of nationally designated areas in mountain massifs



Note: * = Belgium and Germany; ** = the Czech Republic, Austria and Germany.

Map 9.3 Distribution of nationally designated areas in mountain areas



Note: * = Belgium and Germany; ** = the Czech Republic, Austria and Germany.
NDAs in the mountains of Andorra, Albania, Bosnia and Herzegovina, Ireland, Luxembourg, the former Yugoslav Republic of Macedonia, Moldova, Poland and Ukraine are not shown as data are unavailable.

Box 9.4 Kaçkar Mountains National Park, Turkey

Kaçkar Mountains National Park, located in the Caucasus global hotspot (one of the 34 determined by Conservation International) was designated in 1994. It is a Key Biodiversity Area and the sixth largest national park in Turkey, with an area of 51 550 ha (Eken *et al.*, 2006). The park has high geologic, geomorphologic and biodiversity value, and the unique historical, architectural and cultural features characteristic of northeastern Turkey.

Three peaks are higher than 3 000 m, and glaciers still remain. There are 79 glacial lakes larger than 0.5 ha, nine main glacial valleys with average length of 7 km, cirques and moraines (Kurdoglu, 2002). Forest, alpine and subalpine, riverine and lake are the main ecosystems. High mountain forests and natural old forests (4 603 ha) are of particular conservation value; this is the only place in Turkey where rhododendron species can be observed at 3 000 m. The park hosts 661 species, 72 subspecies and 23 varieties of plants, of which 54 are endemic and seven are endangered (Anonymous, 2007). The national park is rich in fauna, with grey wolf, brown bear, wild boar, red fox, roe deer, mountain goat, deer, golden jackal, Caucasian black grouse, Caucasian salamander and rare butterfly species. There are also 149 invertebrate taxa (six endemic species) and 10 amphibian, 28 reptile, 14 freshwater fish, 69 bird and 60 mammal species (Anonymous, 2007).

The park also has unique architectural features, with the best examples of houses, grazing traditions, festivals and handicrafts in the region, as well as many old stone bridges, castles, churches, monasteries and mosques from different periods and civilisations (Acar *et al.*, 2006). There are more than 1 084 houses inside the park, in seven villages, and more than 30 yayla (grazing settlements: see photo below). The number of villagers decreased from 712 in 1980 to 384 in 1990, and 286 in 2000; projections suggest a decrease to 228 in the next 30 years (Anonymous, 2007). Grazing now has only traditional values rather than economic values, as before. In recent decades, as the site has become one of the main tourist attractions of northeastern Turkey, the main income source is now tourism. Tourist pressures are high during the short summer season, and the number of legal protection statuses within the site creates management problems. Other key problems for management and conservation are road construction, illegal utilisation of forests and wildlife, environmental pollution, an increased number of concrete buildings and lack of sufficient staff and equipment (Kurdoglu *et al.*, 2004). To address these issues, the Kaçkar Mountains Management Plan was approved in 2008 and is now being implemented.

Source: Oguz Kurdoglu (Artvin Coruh University, Faculty of Forestry), Yildiray Lise (United Nations Development Programme Turkey Office).

Photo: © Oguz Kurdoglu
Avusor Yayla, Kaçkar Mountains National Park, Turkey.

Table 9.6 Area of nationally designated areas (NDAs) within mountains in EU Member States, by massif (km²)

	NDA % of the country area	Alps	Apennines	Atlantic islands	Balkans/South-east Europe	British Isles	Carpathians	Central middle mountains 1 *	Central middle mountains 2 **	Eastern Mediterranean islands	French/Swiss middle mountains	Iberian mountains	Nordic mountains	Pyrenees	Turkey	Western Mediterranean islands	NDA mountain % of country area
Austria	23	16 754	0	0	0	0	0	0	676	0	0	0	0	0	0	0	21
Belgium	4	0	0	0	0	0	0	21	0	0	0	0	0	0	0	0	0
Bulgaria	3	0	0	0	2 505	0	0	0	0	0	0	0	0	0	0	0	2
Cyprus	32	0	0	0	0	0	0	0	0	2 718	0	0	0	0	0	0	29
Czech Republic	16	0	0	0	0	0	1 848	0	6 781	0	0	0	0	0	0	0	11
Denmark	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Estonia	17	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Finland	9	0	0	0	0	0	0	0	0	0	0	0	3 816	0	0	0	1
France	15	13 739	0	0	0	0	0	166	0	0	25 203	0	0	4 092	0	3 625	9
Germany	42	2 613	0	0	0	0	0	28 087	10 670	0	0	0	0	0	0	0	12
Greece	13	0	0	0	12 547	0	0	0	0	1 733	0	0	0	0	0	0	11
Hungary	9	85	0	0	94	0	2 003	0	0	0	0	0	0	0	0	0	2
Ireland	No data	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	No data
Italy	10	6 486	18 149	0	12	0	0	0	0	0	0	0	0	0	0	890	8
Lithuania	15	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Luxembourg	No data	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	No data
Latvia	18	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Malta	18	0	0	0	0	0	0	0	0	0	0	0	0	0	0	17	5
Netherlands	12	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Poland	No data	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	No data
Portugal	8	0	0	0	0	0	0	0	0	0	0	4 268	0	0	0	0	5
Romania	7	0	0	0	1 360	0	9 410	0	0	0	0	0	0	0	0	0	5
Spain	9	0	0	2 571	0	0	0	0	0	0	0	31 271	0	3 681	0	20	7
Slovakia	23	0	0	0	0	0	10 353	0	0	0	0	0	0	0	0	0	21
Slovenia	12	1 076	0	0	689	0	0	0	0	0	0	0	0	0	0	0	9
Sweden	12	0	0	0	0	0	0	0	0	0	0	0	30 773	0	0	0	7
United Kingdom	13	0	0	0	0	18 225	0	0	0	0	0	0	0	0	0	0	7
NDA % for each massif: EU-27 only		24	16	31	12	26	17	74	40	26	36	14	36	14	3	19	

Note: The first column gives the percentage of the national area designated within NDAs. The last column gives the percentage of the national area of each EU Member State in NDAs in mountain areas. The last row gives the percentage of each massif designated within NDAs within EU Member States.
* = Belgium and Germany; ** = the Czech Republic, Austria and Germany.

Table 9.7 Area of nationally designated areas within mountains in countries outside the European Union, by massif (km²)

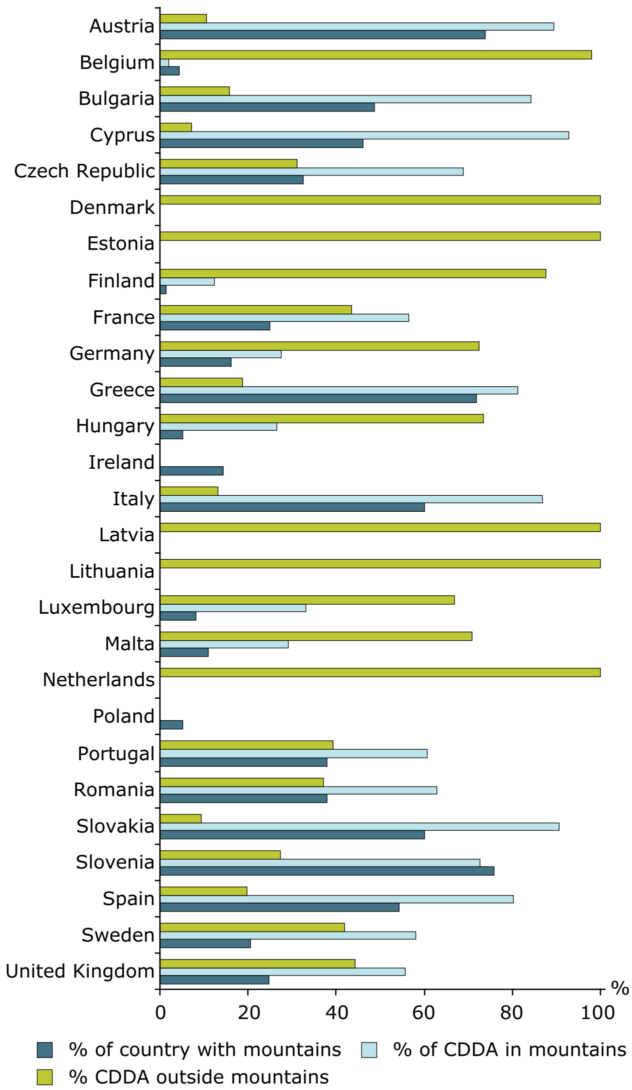
	NDA % of the country area	Alps	Apennines	Atlantic islands	Balkans/South-east Europe	British Isles	Carpathians	Central middle mountains1 *	Central middle mountains 2 **	Eastern Mediterranean islands	French/Swiss middle mountains	Iberian mountains	Nordic mountains	Pyrenees	Turkey	Western Mediterranean islands	NDA mountain % of country area
Albania	No data																No data
Andorra	No data																No data
Bosnia and Herzegovina	No data																No data
Croatia	8.2				3 607												6.4
Former Yugoslav Republic of Macedonia	No data																No data
Iceland	11.1												8 723				8.0
Liechtenstein	42.5	68															42.5
Moldova	No data																No data
Serbia and Montenegro	10.3				8 681												8.5
Norway	14.4												40 110				12.4
Switzerland	23.4	6 637						95			2 456						22.9
Turkey	2.4	0	0	0	0	0	0	0	0	0	0	0	0	0	15 518	0	2
Ukraine	No data						4										No data
Totals for massifs including EU-27 and other countries		25	16	32	9	25	15	74	40	26	34	14	20	14	3	19	

Note: The first column gives the percentage of the national area designated within NDAs. The last column gives the percentage of the national area in NDAs in mountain areas. The last row gives the percentage of each massif designated within NDAs.
* = Belgium and Germany; ** = the Czech Republic, Austria and Germany.

Natura 2000 sites in their mountain area; in most cases the area of NDAs is greater, though this is not the case for Cyprus, Slovenia and Greece, where Natura 2000 sites cover 95 %, 83 % and 82 %, respectively. Of the countries with data, two countries, both with small mountain areas, have less than 20 % of the total area of NDAs in mountains: Belgium (2 %) and Finland (12 %). As with Natura 2000 sites, the ratio relating the percentage of the national area covered by mountains to the percentage of the area of NDAs inside mountains was computed. Countries with a ratio < 1.5 (i.e. the percentage of NDAs located inside mountains is less than 50 % larger than the percentage of mountain coverage) were regarded as having good proportion of NDAs in mountainous areas. These countries were Austria, Belgium, Greece, Italy, Slovenia and Spain. Most of these countries are those that have mountains covering at least half their national area, with the exception of Belgium, which is also the only one of these countries with a ratio of < 1.5 for Natura 2000 sites. All other countries had a ratio > 1.5 (i.e. the percentage of Natura 2000 sites located inside mountains is more than 50 % larger than the percentage of mountain coverage), i.e. an over-representation of NDAs in mountainous areas. Of these countries, the only ones in which mountains cover a high proportion of the national area are Slovakia (60 %), Bulgaria (49 %), Cyprus (46 %) and Romania and Portugal (38 %). As for Natura 2000 sites, ratios were particularly high for Finland (8.3), Hungary (5.2), and Sweden (2.8), showing the high relative importance of mountain ecosystems for biodiversity conservation at both national and European scales in these relatively non-mountainous countries. Two further reasons may be that the mountain areas of these countries, in particular, have been least subject to pressure to use land for other purposes such as agriculture; and hence have also often become state lands or 'common property' allowing for easy designation in comparison to areas under more intensive land use, often under private ownership. Finally, in every country with mountains except for Belgium (ratio 0.44) and Slovenia (0.96), the proportion of area within NDAs was greater than proportion covered by mountains; as for Natura 2000 sites, ratios were also low for Greece (1.13) and Austria (1.21).

National policies for the management of NDAs do not necessarily have the same objectives as those defined in the Habitats and Birds Directives; although management of any Natura 2000 site must comply with this European legislation. It is consequently of value to compare the extent to which designations under national and EU legislation overlap. As can be seen from Figure 9.15, the proportions to which NDAs and Natura 2000 sites overlap in mountain areas vary considerably: 100 % in this graph is the total area covered by NDAs, Natura 2000 sites, or both. As data are lacking for either NDAs, Natura 2000 sites, or both for Austria, Ireland, Poland and the United Kingdom, these countries are not included. The greatest overlap — at least 50 % — is in four countries where mountains cover a rather small proportion of the national area: Finland (87 %), Sweden (72 %), Malta (70 %), and Hungary (56 %). These are rather small areas in terms of extent, but clearly of significant importance at the European

Figure 9.14 EU-27: Percentage of area covered by nationally designated areas inside and outside mountains by country, also indicating the percentage of the national area covered by mountains



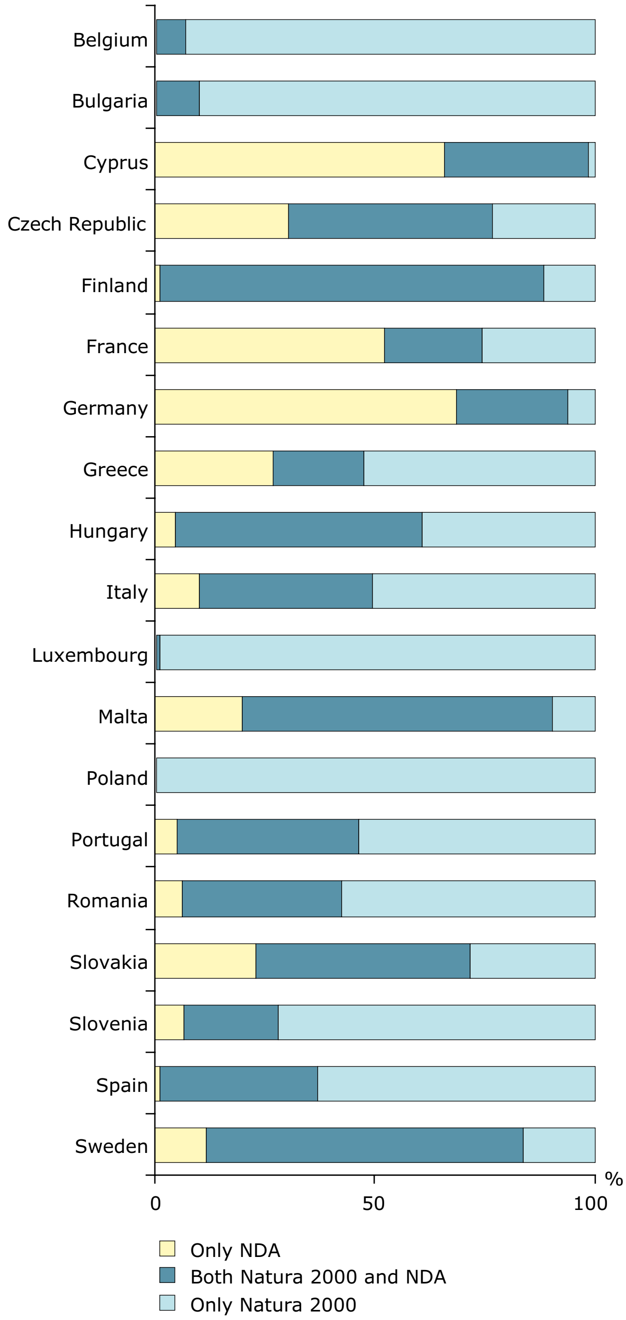
scale. Overlaps are also high in countries with quite a high proportion of mountain area: Slovakia (49 %), the Czech Republic (46 %), and Portugal (41 %). Three countries have a particularly high proportion of their mountain protected area within NDAs: Germany (68 %), Cyprus (66 %) and France (52 %). This suggests a relatively low dependence on EU legislation for the conservation of biodiversity. Conversely, seven have a particularly high proportion of their mountain protected area only within Natura 2000 sites, which suggests a high dependence on EU legislation for biodiversity conservation: Luxembourg (99 %), Bulgaria (90 %), Slovenia (72 %), Spain (63 %), Romania (58 %), Portugal (54 %), and Greece (53 %). There are no clear patterns in these relationships; undoubtedly to some extent they reflect national differences in the process of submitting sites for inclusion in the Natura 2000 network.

9.3 Connectivity and adaptation to climate change

Despite the considerable proportion of Europe's mountains that is within both nationally designated protected areas and the Natura 2000 network, there is increasing recognition that site designation alone may not be adequate to maintain viable populations of many mountain species and functional habitats, given the interacting challenges of land-use change and climate change. As noted in Section 8.3, many mountain species may be at particular risk because of limited habitats and barriers to movement, and most protected areas in mountains are projected to lose suitable conditions for species rather than gain (Araújo, 2009). In addition, the maintenance of functioning ecosystems is essential if they are to continue to provide ecosystem services. Such issues have been recognised through the development of a range of bioregional concepts such as the ecosystem approach, as adopted by the Convention on Biological Diversity (CBD, 2000), connectivity conservation (Worboys *et al.*, 2010) and, in European Union, fragmentation (EEA, 2010) and green infrastructure (Sundseth and Sylwester, 2009).

Mountain areas have been a particular focus of such approaches both globally (Worboys *et al.*, 2010; CBD, 2004) and in Europe, with initiatives in the Alps (Kohler and Heinrichs, 2009) and to adjacent mountain massifs (Box 9.5), the Apennines (Romano, 2010), Carpathians (Zingstra *et al.*, 2009), various mountain ranges in southeast Europe, including the Sharr mountains (Box 9.1),

Figure 9.15 Proportion of national mountain protected area within nationally designated areas, Natura 2000 sites, or both



mountains in Bulgaria and Romania (BirdLife European Forest Task Force, 2009) and the wider mountains around the Mediterranean (Regato and Salman, 2008). The importance of, and progress with, such initiatives was recognised as a result of the In-depth Review of the Implementation of the CBD Programme of Work on Protected Areas (CBD, 2010). Nevertheless, a wide range of challenges have been recognised, particularly the need for clear frameworks for management (Worboys and Lockwood, 2010), effective process management involving the very wide range of stakeholders (Bennett, 2009) and long-term commitment, including monitoring to assess the implementation of such approaches as a part of adaptive management (Price, 2008). In addition to connectivity initiatives, two other types of approach are necessary to promote the conservation of species under climate change (Araújo, 2009). The first type comprises stationary refugia, or range retention areas, where species are most likely to survive despite climate changes. The second type comprises displaced refugia, where species can find suitable habitats after they have been displaced from their original location by climate change. These are typically at the leading edge of species ranges, so that bioclimatic envelope models can be used to identify them. Both types can be found in some mountain ranges, deep valleys, and other areas with steep climate gradients where certain types of climate that become regionally restricted with climate change can persist. Such approaches are key elements in adapting to the impacts of climate change on biodiversity and ensuring the long-term delivery of ecosystem services from Europe's mountains but, as noted more generally with regard to climate

Box 9.5 Cantabrian mountains-Pyrenees-Massif Central-Western Alps Initiative

The purpose of this conservation initiative is to rebuild the ecological linkages between four major western European mountain ranges: the Cantabrian Mountains, the Pyrenees, the Massif Central, and the Alps (Map 9.4). The maximum length of the Initiative is about 1 300 km; the total area is 161 780 km²; and linkages between mountain ranges include 19 000 km². The area includes parts of six countries (Andorra, France, Italy, Portugal, Spain and Switzerland), and 24 different administrative units, of which over half have full political responsibilities concerning land-use planning, agriculture, forestry and nature conservation (Mallarach *et al.*, 2010).

These mountain ranges have exceptional scenic and ecological values. They include little-disturbed landscapes, being the last stronghold for flagship species such as brown bear (*Ursus arctos*), chamois (*Rupicapra rupicapra* and *R. pyrenaica*), ibex (*Capra ibex*), lammergeier (*Gypaetus barbatus*) and capercaillie (*Tetrao urogallus*). Wildlife is significant at both global and regional scales, with numerous endemic and relict species. The cultural heritage is also rich, including a variety of cultural landscapes, with thousands of prehistoric and historic sites, some of them World Heritage Sites. Intangible cultural heritage is also rich, with nine languages, including Basque, Europe's oldest living language. Population is concentrated among and around the mountain ranges. The economy combines pastoral, forest and craft activities with either mass tourism related to ski resorts and second homes, or more sustainable ecotourism.

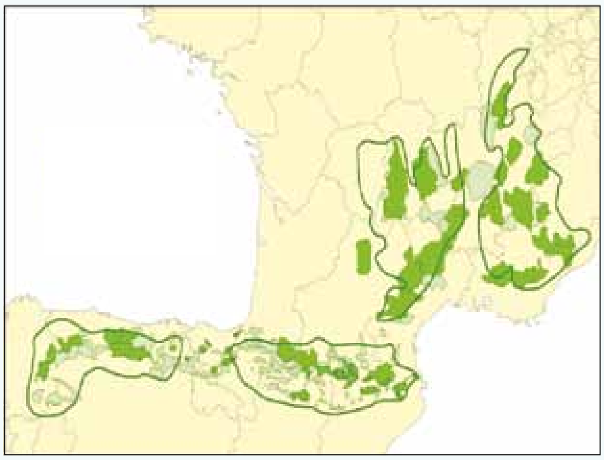
Map 9.4 Mountain ranges involved in the Cantabrian mountains-Pyrenees-Alps Initiative

Within the mountain ranges, threats include: rural depopulation linked to the abandonment of traditional agricultural landscapes, expansion of forests and cultural impoverishment; the fact that, despite difficult economic viability, large ski resorts have major impacts, and some are expanding; and urban sprawl linked to mountain recreation, creating environmental degradation and local population disturbances in a number of valleys. Between the mountain ranges, threats include: road and railway networks fragmenting the landscape; irrigation infrastructure, intensive agricultural uses, and forestry plantations transforming the remaining semi-natural habitats; and artificial areas expanding through urban and industrial development, creating new barriers for wildlife. In addition, climate change is having noticeable impacts on some of the most fragile species and communities, especially in the highest alpine ecosystems.

Box 9.5 Cantabrian mountains-Pyrenees-Massif Central-Western Alps Initiative (cont.)

There are also positive trends. Protected areas have significantly increased, due to Natura 2000, and now cover about 38 % of the Initiative area. However, the heterogeneity of legal protection categories, weak integration of sectoral policies, and insufficient international cooperation undermine conservation effectiveness. Forest expansion, cropland reduction, and rural depopulation are increasing ecological permeability for forest species, including large mammals. Ungulate reintroduction, restocking, and population growth provide the necessary prey for large carnivore recovery, which is already taking place, for example the spontaneous expansion of wolf and lynx populations and the recovery of the Cantabrian brown bear.

Map 9.5 Existing and proposed protected areas within the Cantabrian mountains-Pyrenees-Massif Central-Western Alps Initiative



Existing and proposed protected areas (PA) within the Cantabrian Mountains-Pyrenees-Alps Initiative

Existing PAs

Natura 2000

To identify the geographical scope of the Initiative and its ecological viability, a GIS-based analysis was undertaken: 1) delimitation of the mountain ranges and linkages among them; 2) analysis of fragmentation processes and man-made barriers both within the mountain ranges and between them, identifying critical points; 3) analysis of the distribution of the existing protected areas coverage (Map 9.5); 4) a SWOT analysis. The Initiative has been led by Caixa Catalunya Savings Bank, through its Social Work Foundation, under the auspices of the Council of Europe, with support from the IUCN, Europarc Federation, Eurosite, European Commission DG XI, and Spanish regional and provincial governments. Since 2005, several regional and provincial governments have adopted ecological connectivity strategies or consistent regional land-use plans, including sound systems of ecological corridors.

Lessons learned include: the power of 'thinking big', based on bioregional and ecosystem criteria, overcoming proposals limited by political and administrative barriers; the capabilities of civil society and private organisations to promote and lead international initiatives followed by both public powers and private organisations, when key international organisations provide support; the need for a wide multi-scale and multi-sectoral approach, aimed towards all sectors that may have an impact on ecological connectivity, avoiding a narrow conservation biology focus. The Initiative provides a framework for promoting new and stronger cooperation projects at both national and international levels, aimed toward rebuilding a 'green infrastructure' of continental significance.

Source: Miquel Rafa and Josep M. Mallarach (Foundation Caixa Catalunya, Spain).

change and protected areas, they must take a long-term view. This needs to include integrated management of the wider landscapes including protected areas (as for example, in the many biosphere reserves in mountains areas), supported by better integration across sectors. At the policy level, adaptation to climate change may imply more flexible planning mechanisms for classifying, reclassifying and declassifying protected-area networks, and updating the species and habitats classified under the Birds and Habitats Directives (Araújo, 2009).

10 Integrated approaches to understanding mountain regions

All of the different demographic, socioeconomic, and environmental factors described in the previous chapters interact in complex ways to influence both human populations and the environments on which they depend in various ways. A number of typologies have been developed to in order to provide a greater understanding of such interactions and provide spatial and 'visual' frameworks for scientific analysis and communication to policy-makers and local stakeholders. For instance, the European Commission (EC, 2004) developed a typology of social and economic capital based on three sets of criteria: population development, population density and access to markets. However, this typology did not consider all the mountain regions addressed in the present report. Below, we present three typologies that do consider the majority of these mountains and are based on more recent data and analyses, each linked to providing a better evidence base for specific EU policies.

10.1 Mountains and rurality

The FARO-EU (Foresight Analysis of Rural areas Of Europe) project was a three-year (2007–2010) specific targeted research project funded through the European Commission's 6th Framework Programme (FARO-EU, 2009). The project aimed to answer the following questions: what are major trends and driving forces affecting rural regions; at which scales do they operate; which of these processes are amenable to change through rural development policies and where; and how might rural policies to take account of these processes? One of the key outcomes of the project was the FARO-EU rural typology (Eupen *et al.*, in press), the main role of which is to provide a flexible spatial framework that helps systemise the heterogeneous European rural context and link the different steps of the FARO-EU conceptual framework. Recently, the typology has been described and compared in an overview of five recent European stratifications and typologies that illustrate the most up-to-date methods for classifying the European environment, including their limitations and challenges (Hazeu *et al.*, 2010). The resulting framework enables the determination of which rural areas and situations are comparable and the degree of generalisation that is possible. The typology consists of homogenous units (1 km^2 grid) and has two dimensions which represent:

- biogeographical differences (altitude and climate) based on the Environmental Stratification of Europe (EnS) (Metzger *et al.*, 2005; Jongman *et al.*, 2006);
- socio-economic differences (accessibility and economic density).

Accessibility (in time) is chosen because it is important to distinguish between 'accessible rural' areas and 'remote rural' areas in terms of relational space, the definition being in terms of accessibility rather than geographical location. The economic density dimension is selected to deal with major differences in level of economic power and population density, which has been used to rank countries by their level of development (Gallup *et al.*, 1999), which in turn determines the capacity to compete or take advantage of new opportunities. These two dimensions were addressed in more detail with regard to mountain areas in Chapter 3.

Table 10.1 shows the economic density and accessibility thresholds used to classify the 12 environmental zones (ENZs) into three classes, i.e. low, average and high. The statistical analysis of combining and clustering the socioeconomic dimensions per environmental zone, results in nine classes ranging from low to high accessibility and economic density (see Figure 10.1), which were grouped into three rural types: peri-urban, rural and deep rural (see Figure 10.2).

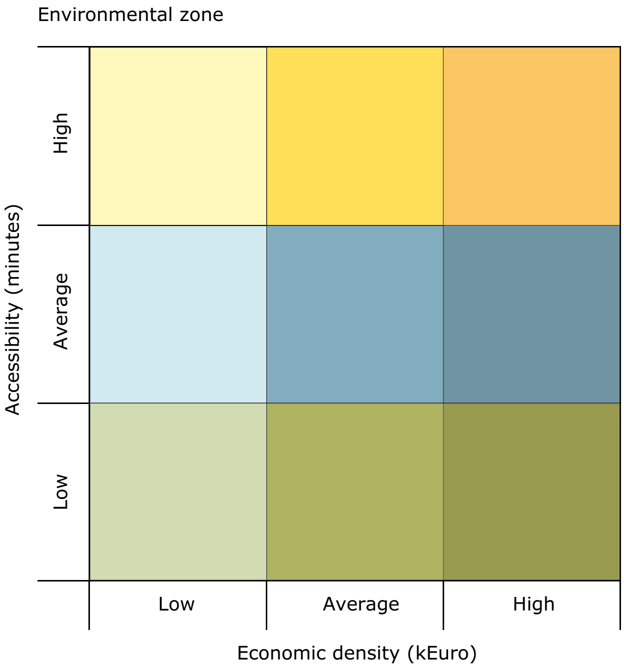
The distribution of FARO-EU rural classes is shown in map form in Map 10.1 and for individual countries in Table 10.2, comparing mountain and non-mountain areas.

According to the FARO-EU topology, most of Europe's mountain areas are classified as deep rural, i.e. they have both a low economic density and a low accessibility. The countries with the highest proportion of deep rural in their mountains are

Table 10.1 Economic density and accessibility thresholds per environmental zone (ENZ)

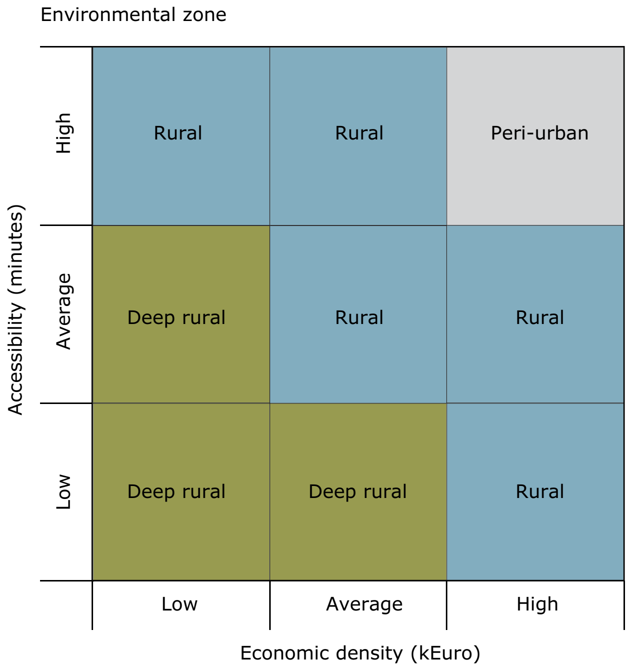
Environmental zone	Economic density (thousand EUR)			Accessibility (minutes)		
	Low	Average	High	Low	Average	High
Atlantic central	< 395	395–2 001	> 2 001	> 80	45–80	< 45
Atlantic north	< 234	234–1 450	> 450	> 85	55–85	< 55
Lusitanian	< 175	175–772	> 772	> 90	55–90	< 55
Mediterranean north	< 99	99–630	> 630	> 90	60–90	< 60
Continental	< 98	98–585	> 585	> 95	65–95	< 65
Mediterranean south	< 97	97–536	> 536	> 100	65–100	< 65
Mediterranean mountains	< 68	68–423	> 423	> 95	70–95	< 70
Alpine south	< 53	53–303	> 303	> 100	70–100	< 70
Nemoral	< 47	47–263	> 263	> 100	70–100	< 70
Boreal	< 44	44–170	> 170	> 105	80–105	< 80
Pannonian	< 34	34–157	> 157	> 120	85–120	< 85
Alpine north	< 0.5	0.5–77	> 77	> 115	100–115	< 100

Figure 10.1 Classifying rural areas: nine classes resulting from the combination of economic density and accessibility within each environmental zone



Source: Eupen *et al.*, in press.

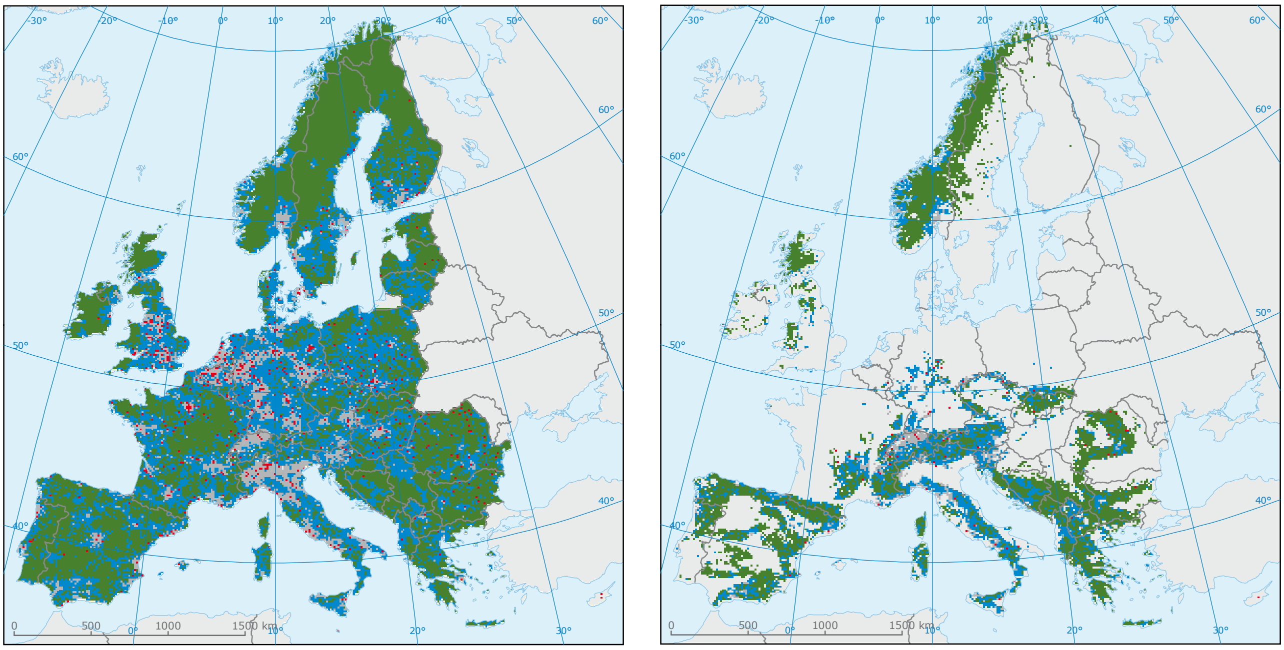
Figure 10.2 Classification of the nine classes into three rural types: peri-urban, rural and deep rural



Source: Eupen *et al.*, in press.

Finland (100 %), Sweden (98 %), Ireland (94 %), Slovakia, the United Kingdom (84 %) and Romania (82 %). In all countries with any significant mountain area, the proportion of deep rural is greater within the mountains than outside, even though this may not be apparent from Map 10.1. However, some European mountain areas have also higher proportions of the other two classes. For example, there is a high proportion of rural in the mountains of Germany (64 %), Slovenia (60 %), Italy (56 %), and Austria (54 %), for the reasons mentioned previously. In Switzerland, a considerable proportion of the country — particularly the highly populated Mittelland, the most accessible mountain

Map 10.1 Distribution of FARO-EU rural classes across Europe and massifs



Distribution of FARO-EU (Foresight Analysis of Rural areas Of Europe) rural classes across Europe and mountains

Peri–urban Rural Deep rural Urban

area in Europe — is classified as peri-urban (and even urban). Peri-urban, and even some urban areas are also found along the edge of the Alps, and even in inner-Alpine valleys. Thus, 29 % of the mountains of Slovenia are peri-urban, 20 % in Germany, 14 % in Italy, and 10 % in Austria — particularly in the Alps, but also (often with small urban areas) in other mountain ranges such as the Apennines of Italy, the lower mountains of Germany; and also in the Massif Central of France.

In conclusion, the high spatial-resolution FARO-EU typology allows the first consistent overview at the pan-European level of the great heterogeneity and diversity of Europe's mountain areas. It reveals that deep-rural regions and wilderness (as described in Section 10.3) coexist with dynamic urban areas over relatively short distances. This is consistent with the conclusion of the European Commission (EC, 2004), which showed the great variation in demographic and socioeconomic variables. Both studies indicate the need to implement different and targeted policy instruments to these 'mountainous spaces' within the same mountain massif rather than uniform policies covering the whole massif. In addition, they show the need for further research to analyse the potential functional interactions between these spaces.

Table 10.2 Distribution of the FARO-EU classes inside and outside the mountain massifs per country

Country	Peri-urban		Rural		Deep rural	
	Inside mountains	Outside mountains	Inside mountains	Outside mountains	Inside mountains	Outside mountains
Austria	10.4 %	44.2 %	53.8 %	40.0 %	34.3 %	11.2 %
Belgium	11.2 %	33.6 %	60.2 %	43.7 %	27.1 %	9.5 %
Bulgaria	0.9 %	1.8 %	17.2 %	27.8 %	80.5 %	66.3 %
Cyprus	No data	No data	No data	No data	No data	No data
Czech Republic	6.0 %	8.2 %	50.1 %	53.3 %	42.5 %	35.6 %
Denmark	No mountains	7.1 %	No mountains	62.3 %	No mountains	26.4 %
Estonia	No mountains	1.0 %	No mountains	18.7 %	No mountains	79.3 %
Finland	0.0 %	3.1 %	0.1 %	23.4 %	99.9 %	72.6 %
France	8.0 %	8.8 %	41.1 %	38.3 %	50.0 %	49.7 %
Germany	20.1 %	26.4 %	63.8 %	56.8 %	13.7 %	11.5 %
Greece	1.4 %	9.6 %	24.5 %	55.8 %	73.8 %	31.7 %
Hungary	6.1 %	9.1 %	43.9 %	54.1 %	48.6 %	33.5 %
Ireland	0.6 %	1.6 %	5.1 %	15.9 %	94.2 %	81.3 %
Italy	14.4 %	53.0 %	55.8 %	36.7 %	29.0 %	4.8 %
Latvia	No mountains	0.6 %	No mountains	20.5 %	No mountains	78.2 %
Lithuania	No mountains	1.4 %	No mountains	52.2 %	No mountains	44.9 %
Luxembourg	2.8 %	9.1 %	84.3 %	79.7 %	9.2 %	6.2 %
Malta	26.9 %	32.1 %	61.5 %	28.1 %	7.7 %	9.0 %
Netherlands	No mountains	28.4 %	No mountains	57.7 %	No mountains	4.6 %
Poland	9.7 %	3.5 %	40.9 %	48.2 %	48.2 %	46.6 %
Portugal	3.6 %	8.4 %	21.8 %	26.2 %	74.3 %	63.4 %
Romania	0.7 %	2.4 %	15.0 %	36.2 %	82.5 %	57.3 %
Slovakia	0.6 %	7.8 %	14.8 %	48.6 %	83.6 %	38.9 %
Slovenia	29.4 %	41.2 %	59.9 %	51.1 %	10.1 %	4.5 %
Spain	3.9 %	10.4 %	27.2 %	38.5 %	68.6 %	49.5 %
Sweden	0.0 %	4.6 %	1.5 %	27.6 %	98.4 %	66.8 %
United Kingdom	2.6 %	17.3 %	13.4 %	48.6 %	83.5 %	27.0 %

10.2 Natural and environmental assets of mountain areas

The *Green Paper on Territorial Cohesion* (EC, 2008) has noted the need to coordinate and integrate different policy actions for specific territories that are functionally defined. One way of doing this is to develop 'new geographies' that support the identity of such territories through the identification of particular assets. One such set is represented by natural and environmental assets; described in the context of spatial planning by the European Commission (EC, 1999) as 'characteristics of ecosystems and other natural areas — their relative importance, sensitivity, size and rarity … (to) supply a basis for the assessment of related functions of different natural assets across Europe'. This section describes the characterisation of regions according to the set of assets listed in Table 10.3. These were selected from a wider range of possible assets because 1) data were available for all EU-27 Member States; 2) they were not significantly correlated with each other.

All the data sets were re-sampled to 10 x 10 km grid cells, and standardised to five classes, as shown in Table 10.4, and assumed to represent a gradient of assets for each cell. Scores were attributed to each class as follows:

- very low assets: average > – 1.5 standard deviations: score = 1
- low assets: average – 0.5 to – 1.5 standard deviations: score = 3
- average assets: average +/– 0.5 standard deviations: score = 6
- high assets: average + 0.5 to 1.5 standard deviations: score = 10

Table 10.3 Natural and environmental assets used for characterisation

Dataset	Description	Source
Rural typologies	Economic density and accessibility	FARO-EU project (see above)
High Nature Value farmlands	Presence of HNV farmlands	Paracchini *et al.* (2008)
Proximity to natural areas	Proximity to natural areas (Natura 2000, CLC semi-natural classes, water) Inverse distance weighted availability of natural areas on an area of 10 km radius, expressed as percentage of the theoretical maximum	Annex to Green Paper on Territorial Cohesion : European Commission (EC, 2008)
Air quality	PM_{10} emissions µg/m³ for the year 2004 Extrapolation of measured values to surface areas	AirBase 4.0 data (EEA, 2010a)
EEA Fast Track Service Precursor on Land Monitoring — Degree of soil sealing 100 m	Percentage of sealed (artificial) area per grid cell	EEA data service (EEA, 2010b)

- very high assets: average > 1.5 standard deviations: score = 15

The input data are classified according to their inherent differences, without a subjective rating of 'good' or 'bad'. For example, areas in northern Scandinavia with a low proportion of farmland also score low with regard to HNV farmland, but this does not mean that these areas have few natural assets.

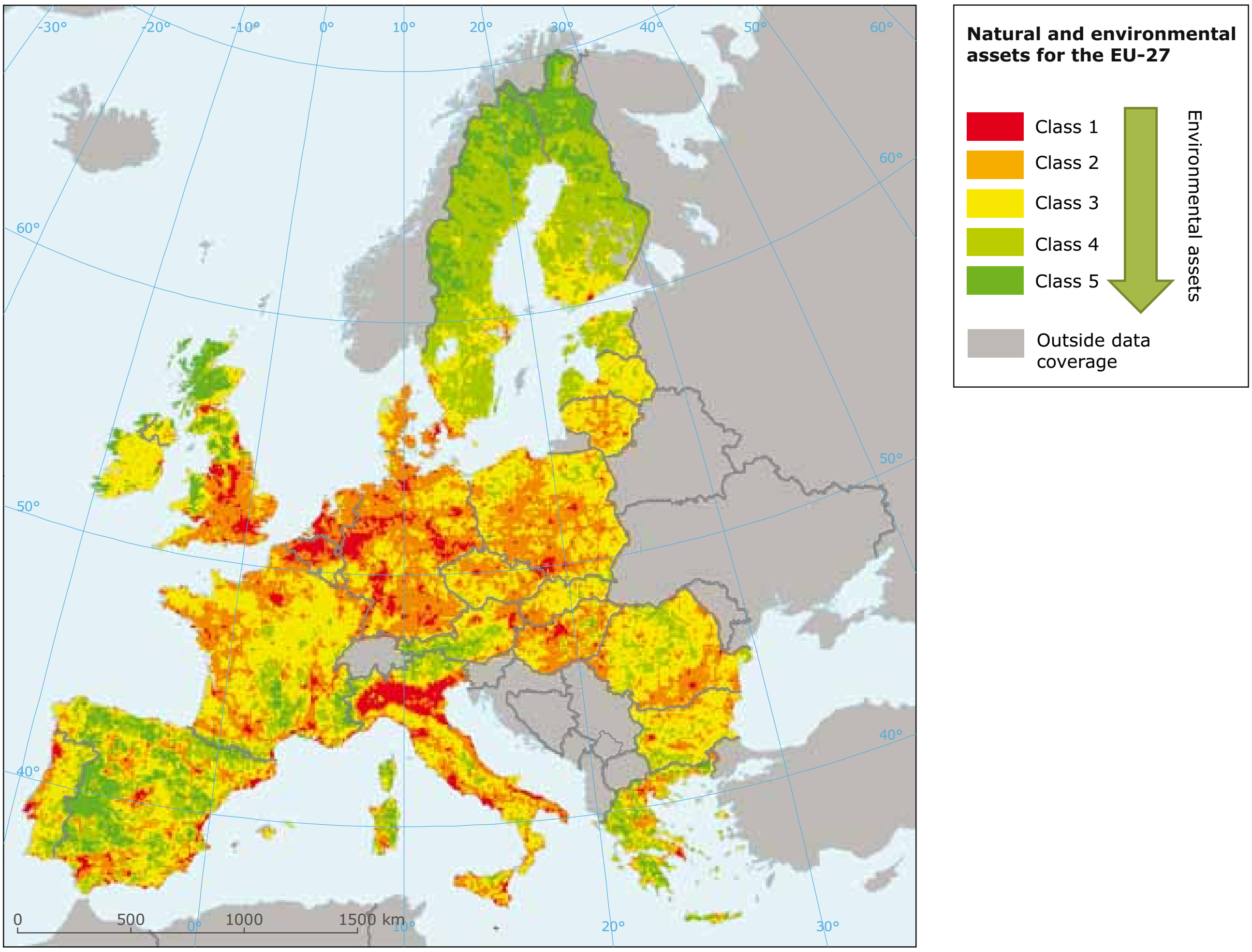
Maps 10.2 and 10.3 present the natural and environmental assets for the EU-27, and mountain massifs within these countries, respectively. Even in Map 10.2 it can be seen that mountain massifs generally stand out; but it should also be noted that there are significant areas with high levels of natural and environmental assets in other parts of the EU-27, including much of Sweden, Finland and Estonia.

Table 10.5 permits a comparison of the relative proportions of natural and environmental assets across the massifs, though considering only the parts within EU Member States. As can be seen in column 2 (data for class 0), large areas in the Nordic mountains (Norway) and the Balkans/South-east Europe are not considered and are not discussed further below; no results are shown for Turkey. The massifs that have very high assets (class 5) over particularly high proportions of their area are those of the British Isles (59 %), western Mediterranean islands (25 %) and Iberian mountains (22 %). Many more massifs have high assets (class 4) over particularly high proportions of their area: Pyrenees (44 %), Iberian mountains (31 %), Alps (29 %), French/Swiss middle

Table 10.4 Thresholds for the definition of classes of natural and environmental assets

Class	**1**	**2**	**3**	**4**	**5**
Asset level	**Very low**	**Low**	**Average**	**High**	**Very high**
Score	**1**	**3**	**6**	**10**	**15**
Rural typologies	Urban	Peri-urban	–	Rural	Deep rural
High Nature Value farmland (%)	0	0–25	25–50	50–75	75–100
Proximity to natural areas (%)	0–4	4–34	34–65	65–95	95–100
Air quality (PM_{10} emissions, µg/m³)	> 56	50–64	30–49	20–29	0–19
Degree of soil sealing (%)	51–100	37–51	23–37	9–23	0–9

Map 10.2 Natural and environmental assets for the EU-27



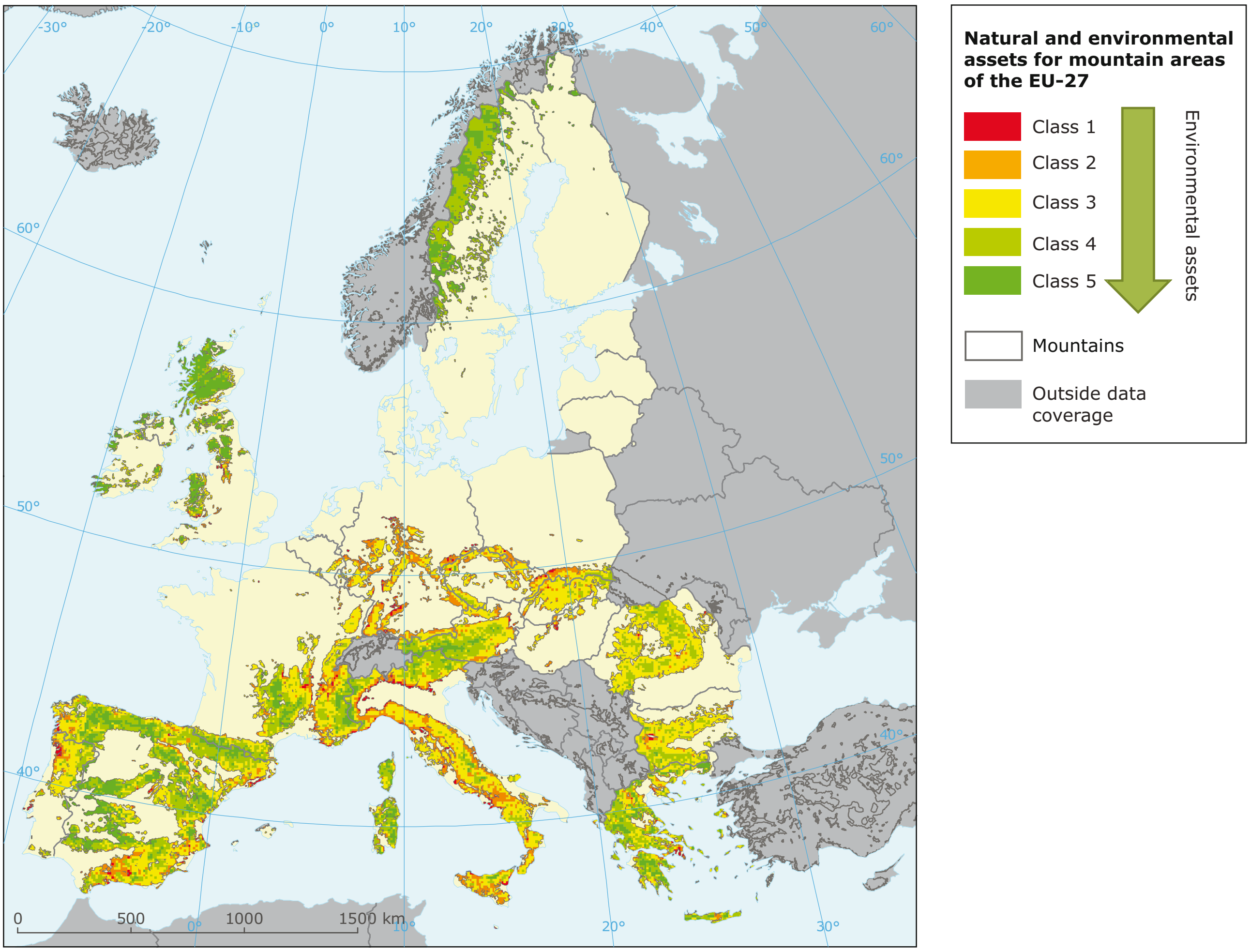
mountains (only France: 28 %) and Carpathians (21 %). The dominant class for most massifs, however, is that of average assets (class 3), which covers more than a third of the area of five massifs: central European middle mountains 2 (60 %), Carpathians (57 %), Apennines (54 %), central European middle mountains 1 (51 %), French/Swiss middle mountains (France only: 42 %). In the class of low assets (class 2), particularly high proportions are only found in the central European middle mountains (1: 44 %, 2: 33 %) and the Apennines (31 %).

In order to provide a greater detail of analysis, Figure 10.3 shows the percentages of the national area of the EU-27 Member States with any significant mountain area (i.e. excluding Estonia, Latvia, Lithuania, Malta and the Netherlands) across the five classes, comparing mountain and non-mountain areas. A clear conclusion from these graphs is that, in every country, the profile of natural and environmental assets, as defined here, is higher in mountain areas than outside mountains.

10.3 Mountains and wilderness

In February 2009, the European Parliament passed a Resolution — with a majority of 538 votes in favour and only 19 votes against — calling for increased protection of wilderness areas in Europe. Three months later, the Czech Presidency and the European Commission hosted a conference in Prague organised by the Wild Europe partnership on 'Wilderness and Large Natural Habitat Areas in Europe'. Over 240 delegates helped draft an agreement to further promote a coordinated strategy to protect and restore Europe's wilderness

Map 10.3 Natural and environmental assets for mountain areas of the EU-27



and wild areas (Coleman and Aykroyd, 2009), see also Chapter 1). This section details the current status of mapping wilderness across Europe as part of this programme and discusses the extent to which wilderness is represented within Europe's mountain areas.

10.3.1 Defining wilderness

Wilderness is just one extreme along a continuum of human modification of the natural environment from the 'paved to the primeval' (Nash, 1982), and may be seen as a relative condition dictated by the degree of naturalness and lack of human influence and intrusion. It is possible to identify and map the wilderness continuum for Europe using GIS methods that take different perceptions of wilderness and associated definitions into account (Carver, 1996; Carver and Fritz, 1999).

Most definitions of wilderness stress the natural state of the environment, the absence of human habitation and the lack of other human related influences and impacts (for example, Leopold, 1921; US Congress, 1964; Hendee *et al.*, 1990). The definition used at the Prague conference is that wild areas 'refer generally to large areas of existing or potential natural habitat, recognising the desirability of progressing over time through increased stages of naturalness — via restoration of native vegetation and a moving towards natural rather than built infrastructure'.

There are relatively few areas of Europe where true wilderness can be found, at least in the sense of the IUCN Classification of Protected Areas (IUCN, 1994) that refers to large areas that are untouched by human activities (Dudley, 2008). Thousands of years of human activity, from early settlement and

Table 10.5 Natural and environmental assets of mountain massifs (km²)

Class	0	1	2	3	4	5	Total (km²)
Alps	28 636	4 530	22 429	60 284	55 937	21 000	192 816
Apennines	2 195	3 073	34 374	60 685	9 635	1 700	111 663
Atlantic islands	8 177	0	0	0	0	0	8 177
Balkans/South-east Europe	176 368	1 394	10 607	61 597	48 703	17 251	315 919
British Isles	3 812	506	2 129	10 225	12 719	42 709	72 100
Carpathians	20 891	1 266	11 510	92 281	34 268	780	160 996
Central European middle mountains 1 *	7	1 916	16 691	19 440	230	0	38 285
Central European middle mountains 2 **	0	686	15 063	27 036	2 348	200	45 332
Eastern Mediterranean islands	8 225	63	918	3 273	3 404	1 483	17 367
French/Swiss middle mountains	9 801	1 041	6 146	34 017	22 941	7 763	81 710
Iberian mountains	2 067	3 135	23 435	94 174	82 726	57 099	262 637
Nordic mountains	310 494	0	10	691	54 920	50 696	416 811
Pyrenees	120	583	3 470	17 070	24 001	9 814	55 058
Western Mediterranean islands	2 611	92	1 223	4 700	9 372	6 046	24 044
Total	573 403	18 285	148 006	485 474	361 205	216 539	

Note: * = Belgium and Germany; ** = the Czech Republic, Austria and Germany.

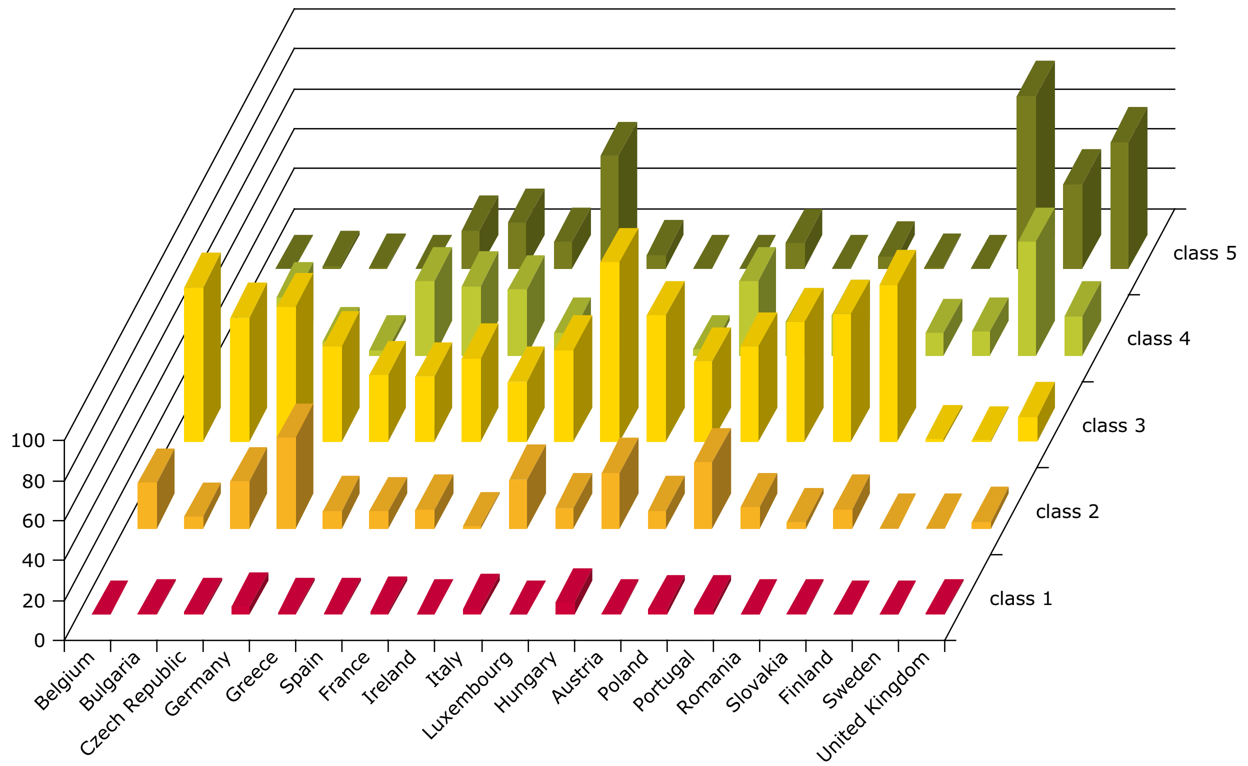
forest clearance for agriculture to the urbanisation and industrialisation of the 19th and 20th centuries has created a rich and varied, but highly modified landscape mosaic across much of the continent. However, wilderness conditions can be seen in certain high-latitude and high-altitude areas, such as parts of Scandinavia and the mountains of central and southern Europe. In addition, smaller, more fragmented wildland areas can be found over a range of intermediate landscapes across the whole of Europe where the original natural ecological conditions have only been slightly modified by grazing, forestry, recreation or isolated human developments.

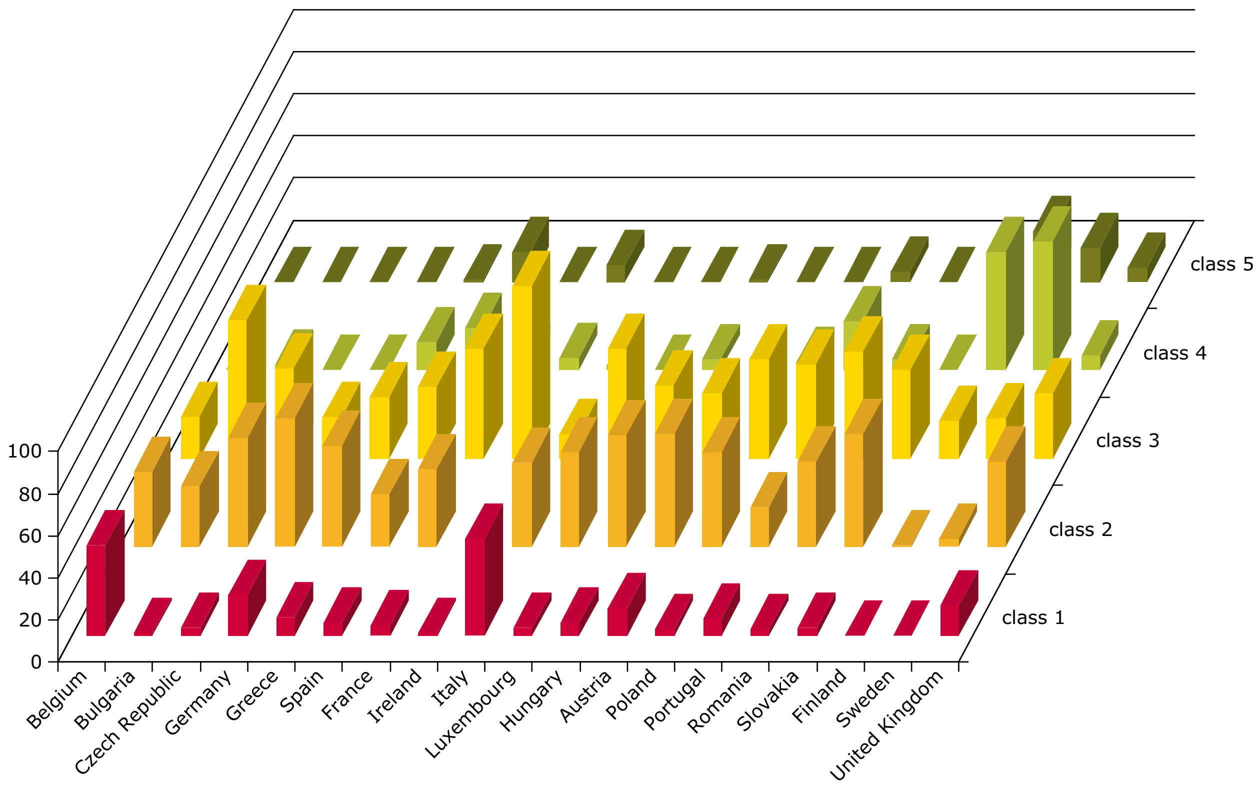
10.3.2 Mapping the wilderness continuum in Europe

GIS can be a valuable tool for wilderness management (Lesslie, 1993; Carroll and Hinrichsen, 1993; Ouren *et al.*, 1994), particularly for mapping, monitoring and analysis. The Australian Heritage Commission (AHC) used GIS to successfully identify wilderness areas for their National Wilderness Inventory on the basis of four attributes: remoteness from settlement, remoteness from access, apparent naturalness and biophysical naturalness (Lesslie, 1994; Miller, 1995). Minimum indicator thresholds were applied to exclude areas that did not meet minimum levels of remoteness and naturalness, thus making an absolute distinction between wilderness and non-wilderness land use.

A more open-ended approach is adopted here, using a less deterministic approach. This is more appropriate for Europe because of the need to be able to identify both large core wilderness areas and the smaller, more fragmented pattern of wildlands across the rest of the continent. On this basis, a more flexible definition of the wilderness continuum based on quantifiable indices and values is required in order to effectively map the environmental characteristics of an area that pertain to wilderness. Thus it is more appropriate to evaluate several wilderness criteria or attributes by considering their different levels of importance. This is achieved by using a multi-criteria evaluation (MCE) approach to investigate a large number of geographical locations in the light of multiple and often conflicting criteria and wilderness values (Janssen and Rietveld, 1990; Carver, 1991; Eastman *et al.*, 1993). MCE methods allow continuous datasets, describing a range of wilderness attributes and conditions, to be combined in a way that best utilises the full range of the data and allows user weights to be applied as a way of describing the relative importance of each input layer. In doing so, it is possible to generate maps that show the spatial variability and geographical patterns in wilderness quality across Europe.

Figure 10.3 Proportion of area of classes of natural and environmental assets within mountains (above) and outside mountains (below) in EU Member States with mountains





Wilderness attribute maps are combined using a simple weighted linear summation MCE model as follows:

$$W_{sum} = \sum_{j=n}^{j} w_j(e_{ij})$$

where:

W_{sum}	=	position on wilderness continuum
w_j	=	j^{th} user-specified attribute weight
e_{ij}	=	standardised score
n	=	number of attributes

Other, more complex, MCE algorithms exist (Carver, 1991), but the weighted linear summation model has the advantages of simplicity and transparency. By applying different attribute maps and weights, different continuum maps can be produced reflecting different model and policy requirements.

A reconnaissance-level wilderness map was produced for the Prague conference in May 2009. Map 10.4 is an updated version of this map using more up-to-date information supplied by the EEA, and has been developed using established methods of combining wilderness attributes as GIS data layers based on MCE techniques (Voogd, 1983; Carver, 1991; Fritz *et al.*, 2000; Carver *et al.*, 2002).

The wilderness attributes used to inform the production of Map 10.4 were each mapped individually using the best available spatial datasets and are as follows:

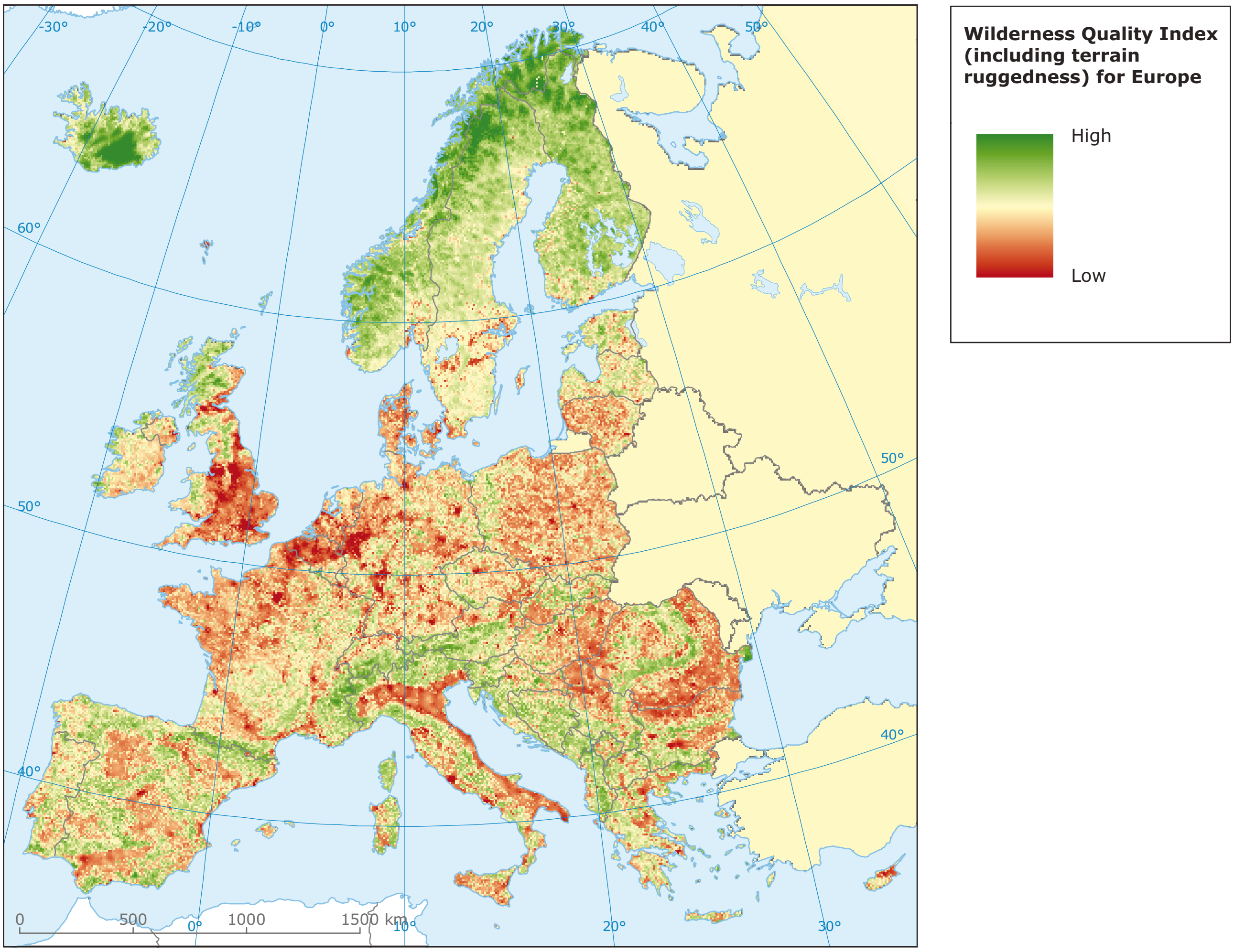
- Population density: data were derived from the Landscan global dataset (ORNL, 2010) see also Chapter 3. Population density is used here as an indicator of likely population pressure on the landscape;
- Road density: derived from the Digital Chart of the World (DCW). This is the United States Defense Mapping Agency's (DMA) Operational Navigation Chart (ONC) 1:1 000 000 scale paper map series (DCW, 1992). While this dataset is not the most current, it has the advantage of being consistent across all European states. Road density was calculated using a 25 km radius kernel density filter and is used here as an indicator of not just road density, but also the likelihood of encountering other human structures such as bridges, dams, power lines, etc., as these are most often found alongside the road network;
- Rail density: derived from the DCW, calculated using a 25 km radius kernel density filter and used here, as with road density, as an indicator of the density of the transportation infrastructure and associated human artefacts;
- Distance from nearest road and railway line: individually derived from the DCW as separate attributes. Linear distance to the nearest road link and railway line are used as indicators of local remoteness and a proxy for likely visual influence on the landscape from modern human artefacts;
- Naturalness of land cover: derived by reclassifying Corine land cover 2000 data (see Chapter 7) into a series of five naturalness classes. The 2000 dataset was used because, unlike the 2006 dataset, it includes data for all countries in Europe. The naturalness of land cover is used as an indicator of the likely level of human disturbance of natural ecosystem function and vegetation patterns;
- Terrain ruggedness: derived from NASA's Shuttle Radar Telemetry Mission (SRTM) digital elevation model data at a resolution of 250 m. The Topographic Ruggedness Index (TRI) (Riley *et al.*, 1999; Evans, 2004) was used to describe the difference in elevation between adjacent cells of a digital elevation grid. Terrain ruggedness is used here as a likely indicator of difficulty of the terrain and associated inaccessibility as well as an indicator of scenic grandeur.

10.3.3 Wilderness in Europe's mountain areas

Numerous permutations of the above wilderness attributes are possible and can be combined using MCE using any number of weighting schemes to reflect particular desired outcomes or policies. The map shown in Map 10.4 is based on a simple equal-weighted combination of population density, road density, distance from nearest road, naturalness of land cover and terrain ruggedness. The top 10 % wildest areas are defined on a simple equal area percentile basis and highlighted in blue. Comparing the resulting map against the distribution of mountain massifs (Map 10.5) demonstrates a high degree of correlation in the general pattern of the core wild areas. This is perhaps unsurprising given the inclusion of ruggedness, which is normally associated with mountainous landscapes. The alternative wilderness continuum map (Map 10.6) leaves out ruggedness and therefore may be more discriminating in its identification of wilderness mountain landscapes, but the underlying pattern of core high latitude and high-altitude areas remains, together with the more fragmented pattern of wildland areas dispersed across the remainder of Europe.

The differences between Maps 10.5 and 10.6 appear mainly in the local detail in that the wilderness

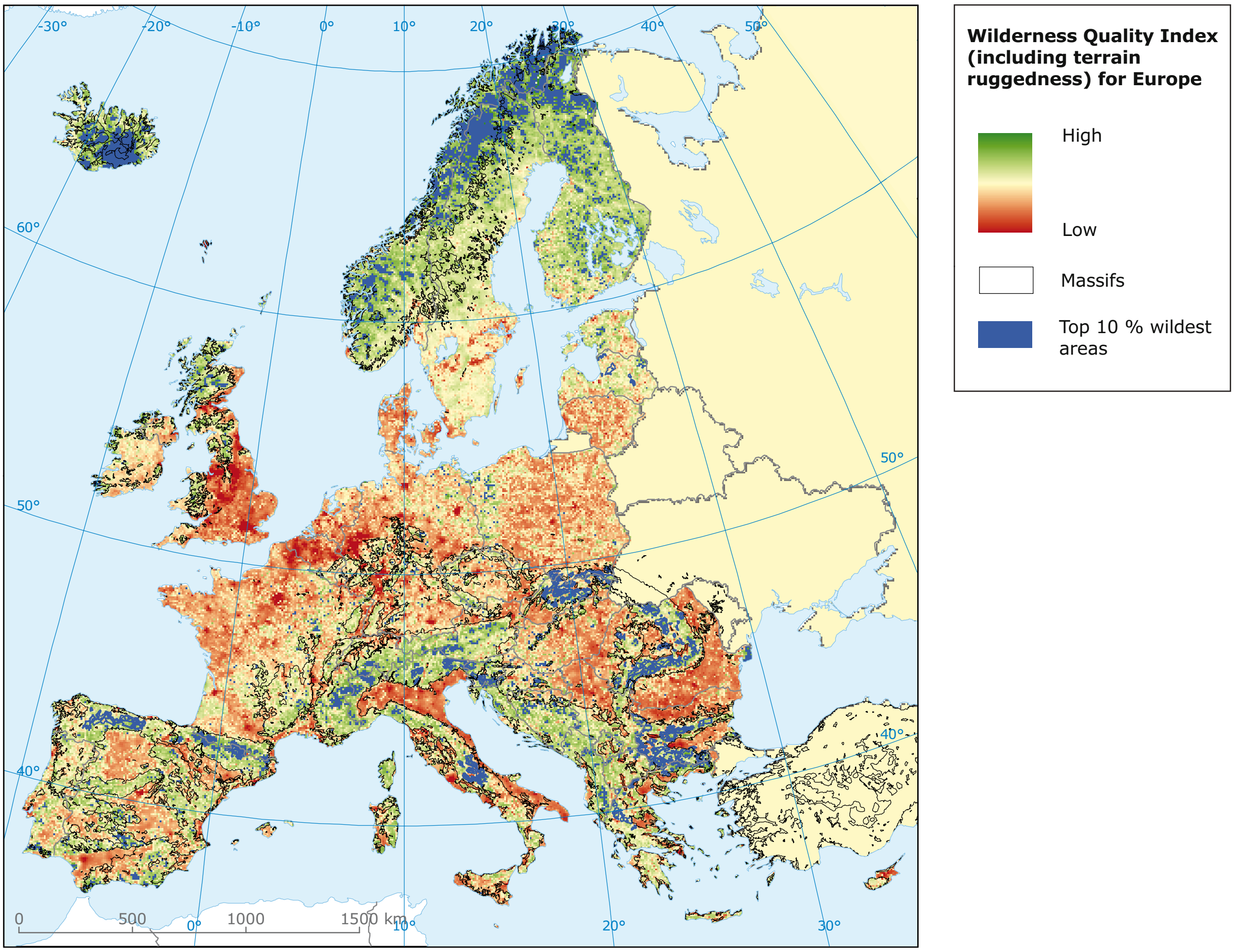
Map 10.4 Wilderness Quality Index (including terrain ruggedness) for Europe



continuum map in Map 10.6 (which excludes terrain ruggedness criteria) becomes more fragmented. This has the result of similarly fragmenting the top 10 % wildest areas in this map, making them appear to cover a larger area when viewed at this broad scale. In addition, the removal of the ruggedness variable leads to a number of lowland areas in Finland being included among the top 10 % wildest areas.

As the Wilderness Quality Index is a continuum, the most appropriate way to compare the extent of wilderness in different massifs and countries is with respect to the top 10 % wildest areas (referred to below as wilderness). Figure 10.4 shows wilderness areas relative to total area of each massif, and Figure 10.5 shows the wilderness areas as a percentage of the area of each massif. Clearly, the Nordic mountains contain by far the largest proportion (28 %) and area of wilderness of all mountain areas in Europe. While the total areas of wilderness are smaller in other massifs, there are notable proportions in other massifs including the Pyrenees (12 %), eastern Mediterranean islands and Alps (9 %), and British Isles (8 %). These patterns are comparable at the national scale (Figures 10.6 and 10.7). It is only in the Nordic countries that wilderness covers both very large areas of mountain land and quite high proportions of national mountain area (Norway 62 946 km², 25 % of national mountain area; Sweden 30 180 km², 33 %; Iceland 23 070 km², 34 %); the only other country with more than 10 000 km² of wilderness is Spain (15 639 km², 6 %). Nevertheless, what is also clear from Figures 10.6 and 10.7 is that, with the sole exception of Finland, wilderness is predominantly in mountain areas, even if the proportion of national mountain area that it covers is less than 10 % — except for the three previously mentioned Nordic countries as well as Hungary (18 %), Albania and Bosnia and Herzegovina (both 12 %), Slovenia (11 %), Ireland and Croatia (both 10 %).

Map 10.5 Wilderness Quality Index (including terrain ruggedness) for Europe, showing massifs and top 10 % wildest areas



Map 10.6 Wilderness Quality Index (excluding terrain ruggedness) for Europe, showing massifs and top 10 % wildest areas

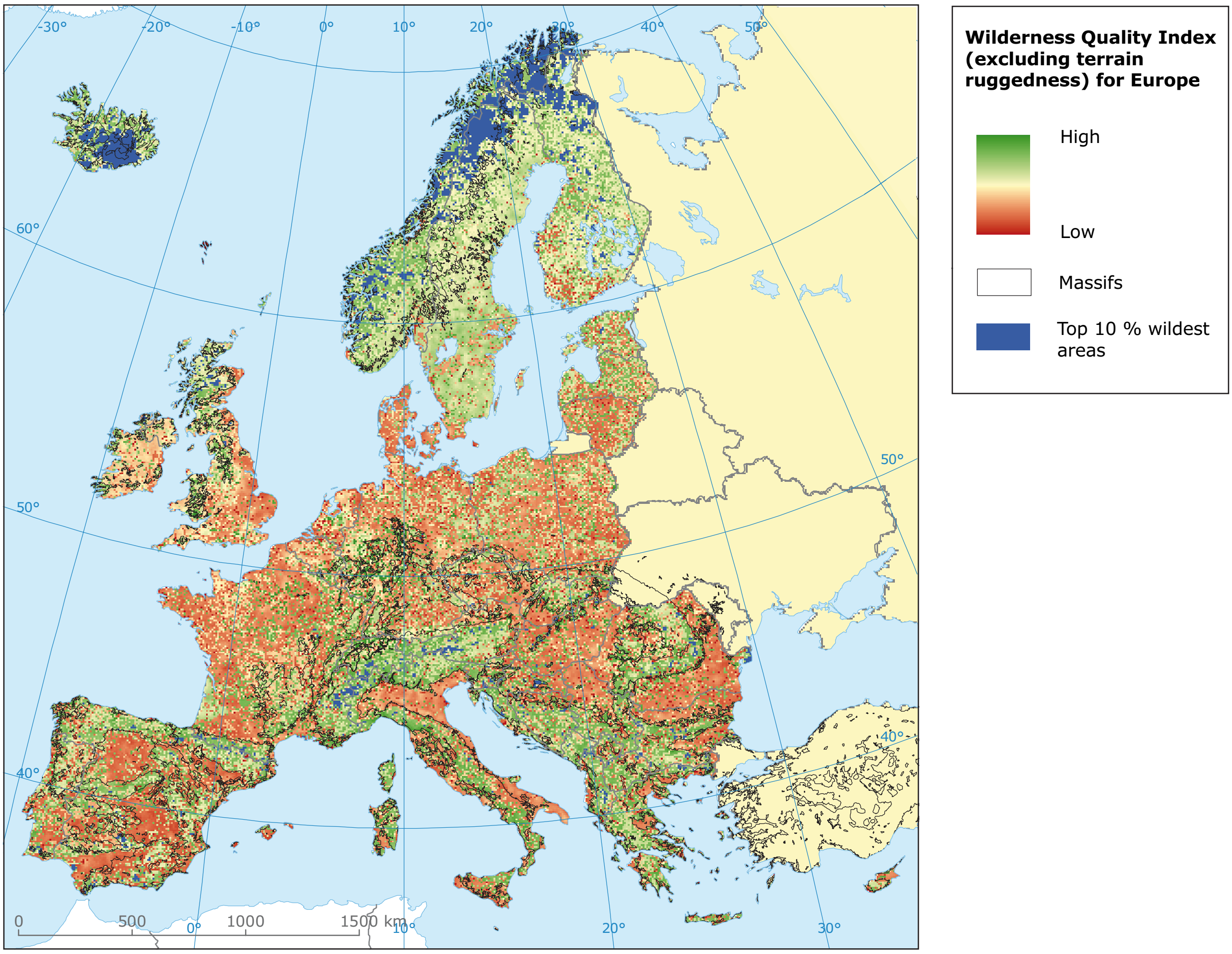
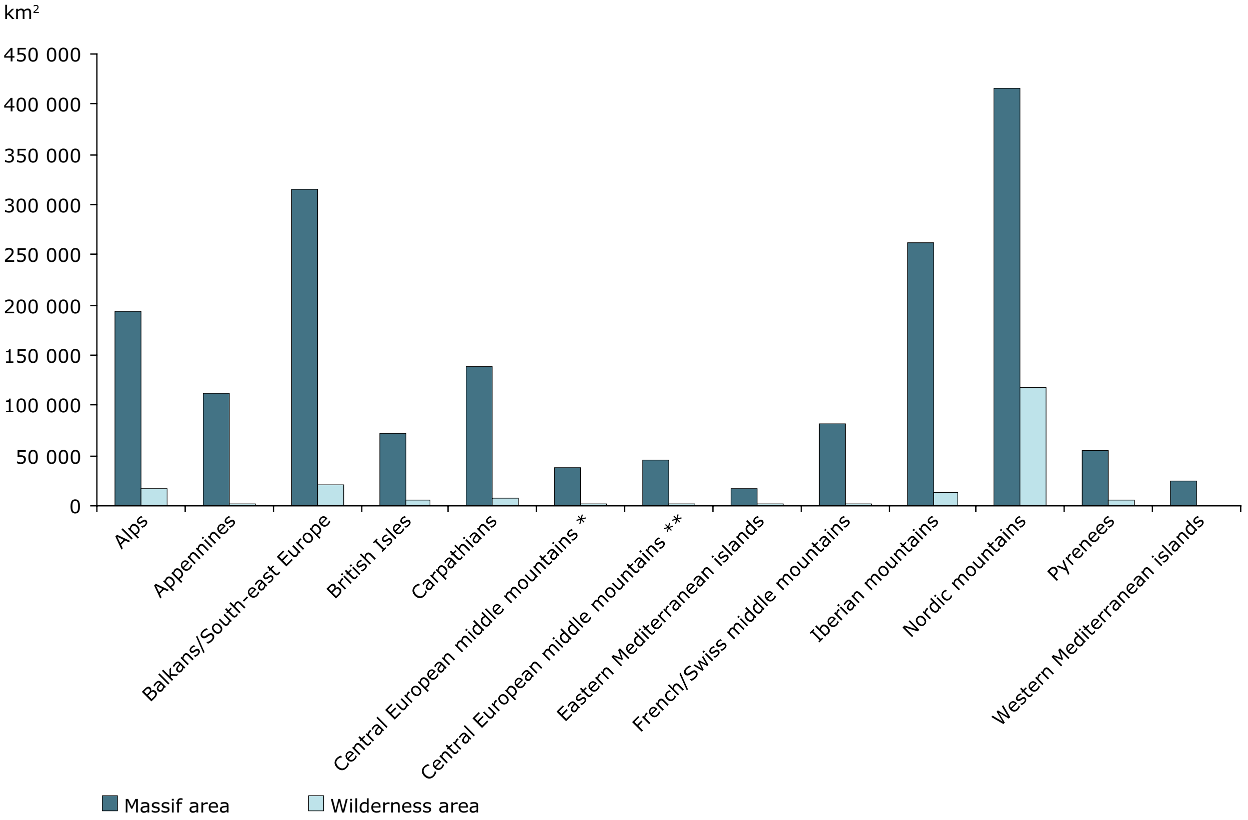
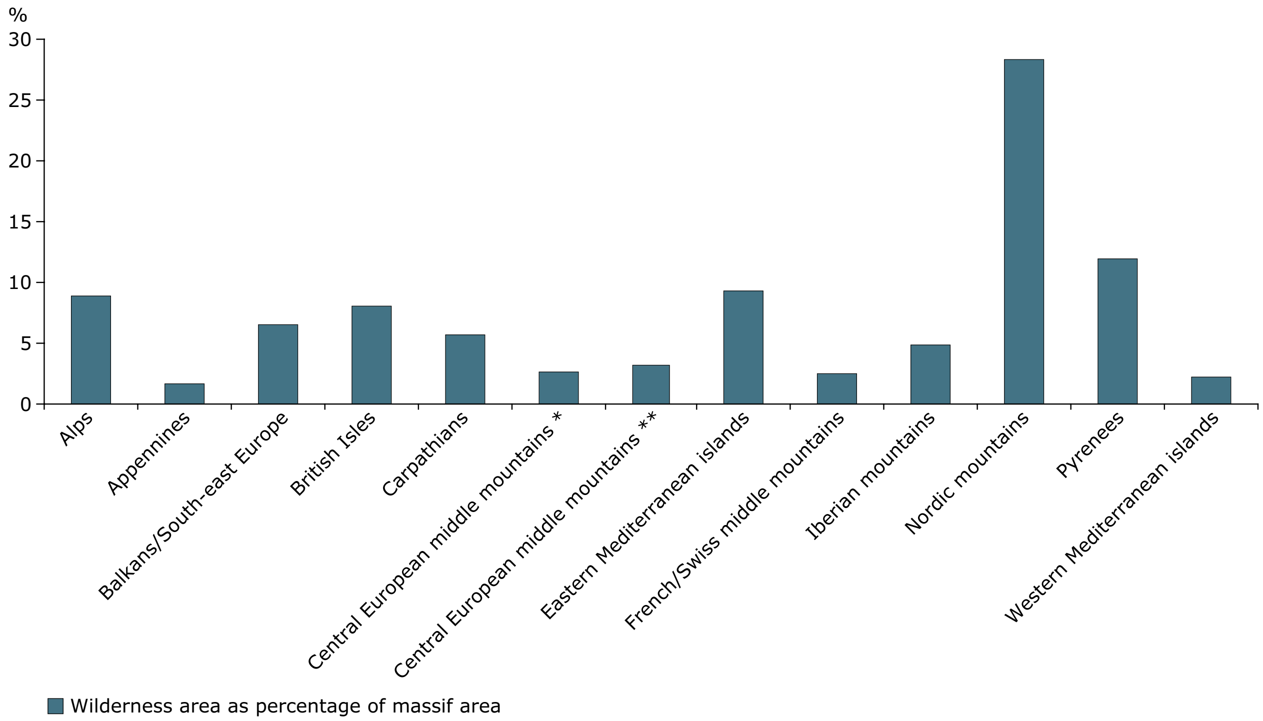


Figure 10.4 Massifs: comparison of area and area of top 10 % wildest areas (wilderness)



Note: * = Belgium and Germany; ** = the Czech Republic, Austria and Germany.

Figure 10.5 Massifs: area of top 10 % wildest areas (wilderness) as a proportion of total massif area



Note: * = Belgium and Germany; ** = the Czech Republic, Austria and Germany.

Figure 10.6 EU-27 Member States: wild mountains (top 10 % wildest areas, or wilderness, in mountains) as proportion of all wilderness in countries and of national mountain area

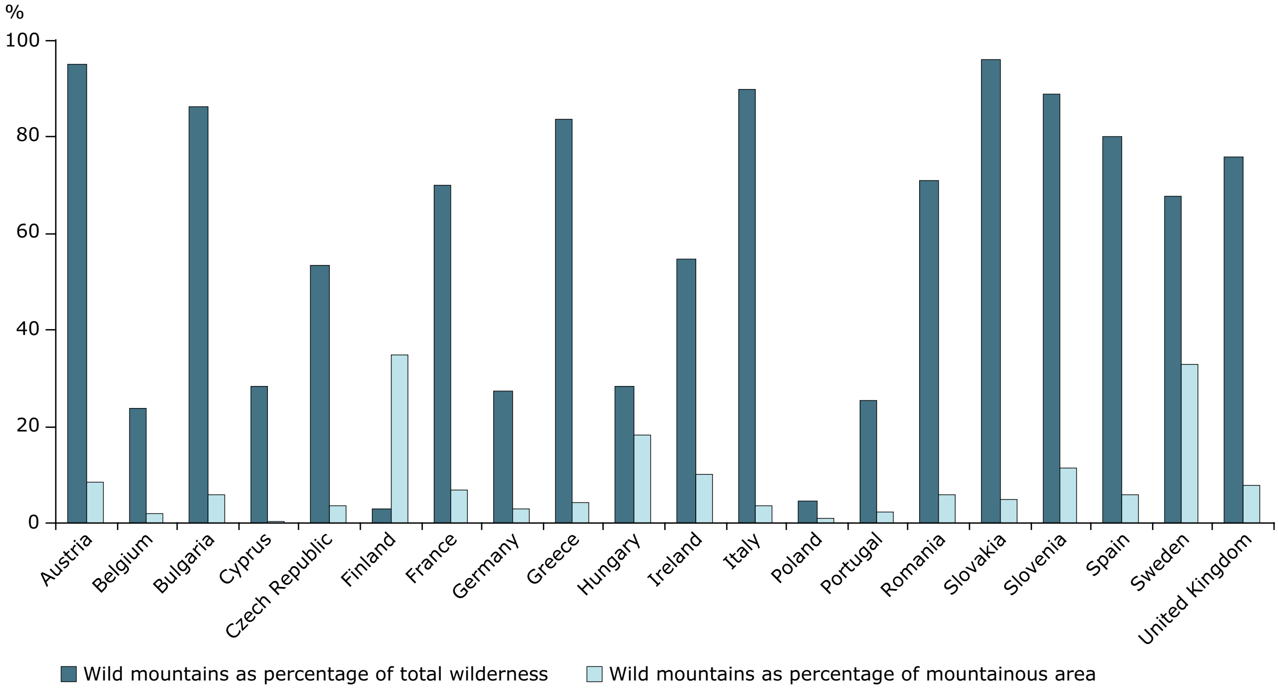
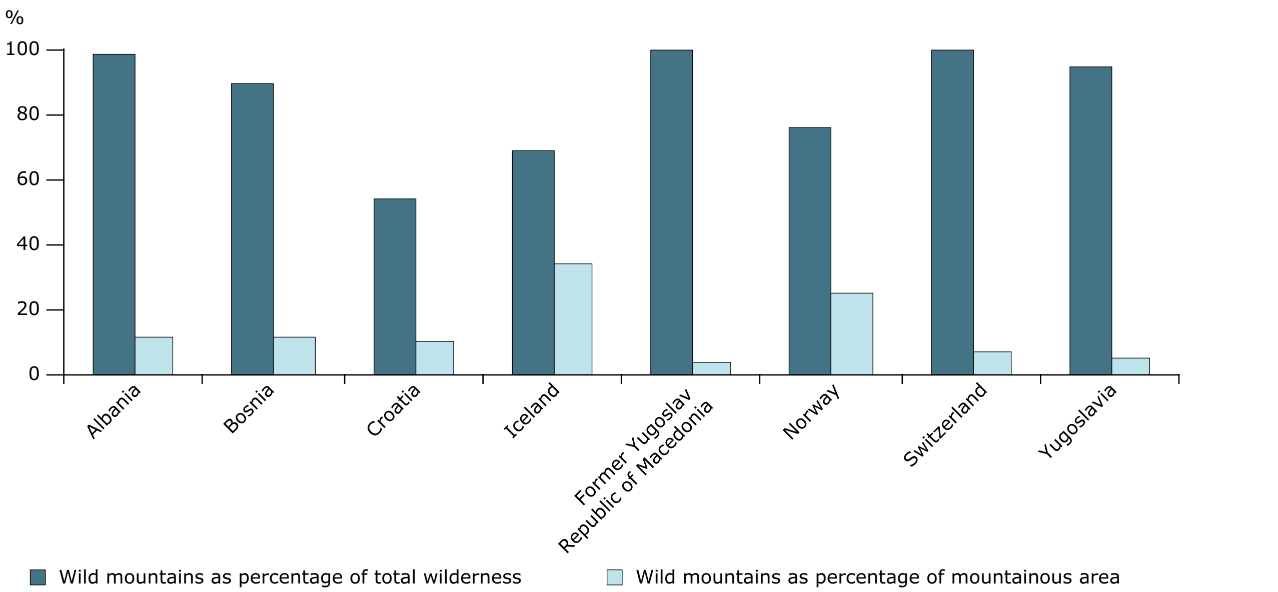


Figure 10.7 Non-EU-27 countries: wild mountains (top 10 % wildest areas, or wilderness, in mountains) as proportion of all wilderness in countries and of national mountain area



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Chapter 5

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Chapter 6

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Appendix 1 Mountain species in the Habitats Directive

Species code ([a])	Species	Annex II	Annex II* ([b])	Annex IV	Category ([c])	Habitat type	Endemic to BGR ([d])	Endemic to C ([e])	Endemic to Other
Invertebrates									
15678	*Agriades glandon aquilo*	1			P				
45	*Baetica ustulata*	1		1	P		MED	ES	Sierra Nevada
54	*Callimorpha quadripunctaria*	1	1		S				
61	*Carabus olympiae*	1	1	1	P		ALP	IT	Alps
91	*Coenagrion hylas*	1			P				
94	*Coenonympha hero*			1	P				
116	*Discus guerinianus*	1		1	P		MAC	PT	Madeira
123	*Erebia calcaria*	1		1	P		ALP		Alps
125	*Erebia christi*	1		1	P		ALP		Alps
128	*Erebia sudetica*			1	P				
143	*Fabriciana elisa*			1	P		MED		
16141	*Graellsia isabellae*	1			P				
15679	*Hesperia comma catena*	1			S		ALP		
191	*Hyles hippophaes*			1	S				
196459	*Leptidea morsei*	1		1	S				
274	*Papilio alexanor*			1	S				
	Papilio alexanor alexanor			1	S				
278	*Papilio hospiton*	1		1	S		MED		
284	*Parnassius apollo*			1	P				
301	*Plebicula golgus*	1		1	P		MED	ES	Sierra Nevada
196465	*Polyommatus eroides*	1		1	P				
305	*Proserpinus proserpina*			1	S				
196435	*Pseudogaurotina excellens*	1	1	1	P				Carpathians
Fish and lampreys									
497	*Eudontomyzon danfordi*	1			P				Tisza and Timis rivers
8670	*Eudontomyzon mariae*	1			P				
523	*Lampetra planeri*	1			P				
530	*Lethenteron zanandreai*	1			S				
554	*Padogobius nigricans*	1			P			IT	
15116	*Phoxinellus prespensis*	1			S				Prespa Lake
10077	*Romanichthys valsanicola*	1	1	1	P			RO	
587	*Rutilus frisii meidingeri*	1			P				
594	*Sabanejewia aurata*	1			P				
604	*Salmo macrostigma*	1			P				
606	*Salmo marmoratus*	1			P				
Amphibians									
635	*Alytes muletensis*	1	1	1	P	foraging	MED	ES	Mallorca
669	*Discoglossus montalentii*	1		1	S	foraging	MED	FR	Corsica
681	*Euproctus asper*			1	P				Iberian
682	*Euproctus montanus*			1	P		MED	FR	Corsica
683	*Euproctus platycephalus*			1	P		MED	IT	Sardinia
697	*Hydromantes ambrosii*	1		1	S	foraging	MED		
698	*Hydromantes flavus*	1		1	S	foraging	MED	IT	
699	*Hydromantes genei*	1		1	S	foraging	MED	IT	
700	*Hydromantes imperialis*	1		1	S	foraging	MED	IT	Sardinia

Species code ([a])	Species	Annex II	Annex II* ([b])	Annex IV	Category ([c])	Habitat type	Endemic to BGR ([d])	Endemic to C ([e])	Endemic to Other
701	*Hydromantes italicus*			1	S	foraging		IT	Apennine
702	*Hydromantes strinatii*	1		1	S	foraging			
703	*Hydromantes supramontis*	1		1	S	foraging	MED	IT	Sardinia
650	*Chioglossa lusitanica*	1		1	S				
744	*Mertensiella luschani*	1		1	S		MED		
780	*Rana graeca*			1	S	foraging			
788	*Salamandra atra*			1	S	foraging			
791	*Salamandra lanzai*			1	P		ALP		Alps
794	*Salamandrina terdigitata*	1		1	S	foraging		IT	Apennine
822	*Triturus karelinii*			1	S	foraging			
Reptiles									
653	*Coluber caspius*			1	S				
663	*Coronella austriaca*			1	S				
716	*Lacerta bedriagae*			1	O		MED		
718	*Lacerta bonnali*	1		1	P		ALP		
719	*Lacerta danfordi*			1	S				
723	*Lacerta graeca*			1	S		MED	GR	
725	*Lacerta horvathi*			1	P		ALP		
726	*Lacerta monticola*	1		1	P				
730	*Lacerta schreiberi*	1		1	S				Iberian
803	*Stellio stellio*			1	P				
812	*Testudo marginata*	1		1	S		MED		
Mammals									
1363	*Barbastella barbastellus*	1		1	S	foraging			
11241	*Bison bonasus*	1	1	1	S				
1367	*Canis lupus*	1	1	1	S				
1368	*Capra aegagrus*	1		1	P				
1374	*Capra pyrenaica pyrenaica*	1	1	1	P		ALP	ES	
1393	*Eptesicus nilssonii*			1	S	foraging			
1403	*Felis silvestris*			1	O				
1407	*Galemys pyrenaicus*	1		1	S				
1438	*Lynx lynx*	1		1	S				
1442	*Lynx pardinus*	1	1	1	S		MED		
196482	*Marmota marmota latirostris*	1	1	1	P		ALP		High Tatras
8350	*Microtus tatricus*	1		1	P		ALP		Carpathians
1519	*Pipistrellus savii*			1	S	foraging			
1553	*Rupicapra pyrenaica ornata*	1	1	1	P				
1555	*Rupicapra rupicapra balcanica*	1		1	P		ALP		Balcans
17283	*Rupicapra rupicapra tatrica*	1	1	1	P		ALP		High Tatras
1562	*Sicista betulina*			1	S				
1568	*Ursus arctos*	1	1	1	P				
Mosses and liverworts									
2290	*Bruchia vogesiaca*	1		1	O				
2318	*Buxbaumia viridis*	1		1	S				
2600	*Cephalozia macounii*	1		1	S				
2856	*Cynodontium suecicum*	1		1	S				
2995	*Dicranum viride*	1		1	S				
3029	*Distichophyllum carinatum*	1		1	P				
3998	*Leucobryum glaucum*			1	S				
4273	*Mannia triandra*	1		1	S				
4283	*Marsupella profunda*	1	1	1	S				
4352	*Meesia longiseta*	1		1	S				
196484	*Ochyraea tatrensis*	1		1	P		ALP	SK	Carpathians
4724	*Orthothecium lapponicum*	1		1	P				
4725	*Orthotrichum rogeri*	1		1	S				
4925	*Plagiomnium drummondii*	1		1	S				
5364	*Riccia breidleri*	1		1	P		ALP		Alps

Species code ([a])	Species	Annex			Category ([c])	Habitat type	Endemic to		
		II	II* ([b])	IV			BGR ([d])	C ([e])	Other
5561	*Scapania massalongi*	1		1	P				
5866	*Sphagnum pylaisii*	1		1	O				
5968	*Tayloria rudolphiana*	1		1	P				
6072	*Tortella rigens*	1		1	S				
Ferns									
150141	*Asplenium hemionitis*			1	S				
150143	*Asplenium jahandiezii*	1		1	O		MED	FR	Alps
150279	*Botrychium simplex*	1		1	S				
150196	*Culcita macrocarpa*	1		1	S				
150213	*Isoetes azorica*	1		1	O		MAC	PT	Azores
150164	*Woodwardia radicans*	1		1	O				
Flowering plants									
150638	*Abies nebrodensis*	1	1	1	P		MED	IT	Sicily
165316	*Adenophora lilifolia*	1		1	O				
177335	*Adonis distorta*	1		1	P			IT	Appenines
164609	*Alyssum pyrenaicum*	1		1	P		ALP	FR	Pyrenees
1801	*Anagyris latifolia*	1	1	1	S		MAC	ES	Canary Islands
178990	*Androsace cylindrica*			1	P		ALP		Pyrenees
178909	*Androsace pyrenaica*	1		1	P		ALP		Pyrenees
1864	*Anthyllis lemanniana*	1		1	P		MAC	PT	Madeira
177369	*Aquilegia alpina*			1	P				Alps
177258	*Aquilegia bertolonii*	1		1	P				
195501	*Aquilegia pyrenaica ssp. cazorlensis*	1	1	1	P		MED	ES	
9118	*Arabis kennedyae*	1	1	1	P		MED	CY	Troodos
163008	*Arabis sadina*	1		1	S		MED	PT	
163356	*Arabis scopoliana*	1		1	P		ALP	SI	Dinaric
194679	*Arceuthobium azoricum*	1		1	O		MAC	PT	Azores
166048	*Arenaria humifusa*	1		1	P				
166392	*Arenaria nevadensis*	1	1	1	P		MED	ES	
15746	*Argyranthemum winterii*	1		1	O		MAC	ES	Canary Islands
154156	*Artemisia granatensis*	1	1	1	P		MED	ES	
154315	*Artemisia laciniata*	1	1	1	S				
155497	*Aster pyrenaeus*	1	1	1	P				Pyrenees
2115	*Aster sorrentinii*	1	1	1	S		MED	IT	Sicily
2121	*Astragalus aquilanus*	1	1	1	P			IT	
171197	*Astragalus centralpinus*	1		1	P				
15765	*Astragalus macrocarpus ssp. lefkarensis*	1	1	1	O		MED	CY	
171244	*Astragalus tremolsianus*	1		1	P		MED	ES	Sierra de Gador
152348	*Athamanta cortiana*	1		1	P		MED	IT	Alps
185085	*Atropa baetica*	1	1	1	P		MED		
2210	*Bencomia brachystachya*	1	1	1	S		MAC	ES	Canary Islands
2211	*Bencomia sphaerocarpa*	1		1	S		MAC	ES	Canary Islands
186350	*Borderea chouardii*	1	1	1	P		MED	ES	Pyrenees
9121	*Brassica hilarionis*	1		1	O		MED	CY	
164405	*Brassica insularis*	1		1	O		MED		
163281	*Braya linearis*	1		1	P				
192156	*Bromus grossus*	1		1	O				
151439	*Bupleurum capillare*	1	1	1	S		MED	GR	
2312	*Bupleurum handiense*	1		1	O		MAC	ES	Canary Islands
2315	*Bupleurum kakiskalae*	1	1	1	P		MED	GR	Crete
191475	*Calamagrostis chalybaea*	1		1	S				
189456	*Calypso bulbosa*	1		1	S				
165248	*Campanula bohemica*	1	1	1	P		CON		Krkonose
165188	*Campanula gelida*	1	1	1	P		CON	CZ	Hrubý Jeseník
165123	*Campanula morettiana*			1	S		ALP	IT	Alps
165056	*Campanula sabatia*	1	1	1	O			IT	

Species code ([a])	Species	Annex			Category ([c])	Habitat type	Endemic to		
		II	II* ([b])	IV			BGR ([d])	C ([e])	Other
165027	*Campanula serrata*	1	1	1	P				Carpathians
164979	*Campanula zoysii*	1		1	P		ALP		Alps
187842	*Carex holostoma*	1		1	P				
153956	*Centaurea alba ssp. Princeps*	1	1	1	P		MED	GR	
154886	*Centaurea attica ssp. megarensis*	1	1	1	S		MED	GR	
2522	*Centaurea citricolor*	1	1	1	S		MED	ES	
2530	*Centaurea gadorensis*	1		1	P		MED	ES	Iberic
154373	*Centaurea lactiflora*	1	1	1	S		MED	GR	
154488	*Centaurea micrantha ssp. herminii*	1		1	P			PT	
2564	*Centaurea pulvinata*	1		1	P		MED	ES	Iberic
155572	*Centaurea rothmalerana*	1		1	P		MED	PT	
184869	*Centranthus trinervis*	1		1	P		MED		Corse, Sardinia
166797	*Cerastium dinaricum*	1		1	P				Dinaric
2708	*Cirsium latifolium*	1		1	O		MAC	PT	Madeira
2720	*Cistus chinamadensis*	1		1	P		MAC	ES	Canary Islands
162876	*Cochlearia tatrae*	1	1	1	P		ALP		Tatra Mts
164020	*Coincya rupestris*	1	1	1	P		MED	ES	
2758	*Consolida samia*	1	1	1	P		MED	GR	
2765	*Convolvulus massonii*	1	1	1	O		MAC	PT	Madeira
162878	*Coronopus navasii*	1	1	1	P		MED	ES	
2806	*Crambe arborea*	1	1	1	S		MAC	ES	Canary Islands
2808	*Crambe laevigata*	1		1	O		MAC	ES	Canary Islands
154703	*Crepis crocifolia*	1	1	1	P		MED	GR	Pelloponesos
2821	*Crepis granatensis*	1		1	P		MED	ES	Iberian
9282	*Crocus cyprius*	1		1	P		MED	CY	
186421	*Crocus etruscus*			1	S			IT	
9283	*Crocus hartmannianus*	1		1	S		MED	CY	
196478	*Cyclamen fatrense*	1	1	1	P		ALP	SK	Carpathians
189484	*Cypripedium calceolus*	1		1	S				
316102	*Dactylorhiza kalopissii*	1		1	S				Balkan
184620	*Daphne arbuscula*	1	1	1	P		ALP	SK	Carpathians
9107	*Delphinium caseyi*	1	1	1	P		MED	CY	
2948	*Dendriopoterium pulidoi*	1		1	O		MAC	ES	Canary Islands
2960	*Deschampsia maderensis*	1		1	S		MAC	PT	Madeira
167427	*Dianthus nitidus*	1	1	1	P		ALP		
163642	*Draba cacuminum*	1		1	P				
163219	*Draba dorneri*	1		1	P		ALP	RO	Carpathians
3084	*Echium gentianoides*	1	1	1	P		MAC	ES	Canary Islands
187643	*Eleocharis carniolica*	1		1	S				
169562	*Erica scoparia ssp. azorica*	1		1	S		MAC	PT	Azores
154037	*Erigeron frigidus*	1		1	P		MED	ES	
172626	*Erodium astragaloides*	1	1	1	P		MED	ES	
3180	*Erodium paularense*	1		1	P		MED	ES	
172623	*Erodium rupicola*	1	1	1	P		MED	ES	
151319	*Eryngium alpinum*	1		1	P				
152254	*Eryngium viviparum*	1	1	1	S				
3232	*Euphorbia lambii*	1		1	O		MAC	ES	Canary Islands
170157	*Euphorbia nevadensis*			1	P		MED	ES	
170067	*Euphorbia stygiana*	1		1	S		MAC	PT	Azores
184461	*Euphrasia azorica*	1	1	1	S		MAC	PT	Azores
3252	*Euphrasia genargentea*	1	1	1	P		MED		
184206	*Euphrasia grandiflora*	1		1	S		MAC	PT	Azores
191810	*Festuca elegans*	1		1	S				Iberian
191561	*Festuca henriquesii*	1		1	P		MED	PT	
198853	*Festuca summilusitana*	1		1	P				Iberian
189110	*Fritillaria drenovskii*			1	P				Balkan
189117	*Fritillaria gussichiae*			1	S				Balkan

Species code (a)	Species	Annex II	Annex II* (b)	Annex IV	Category (c)	Habitat type	Endemic to BGR (d)	Endemic to C (e)	Endemic to Other
182193	*Galium sudeticum*	1	1	1	P		CON		Krkonose
182212	*Galium viridiflorum*	1	1	1	S		MED	ES	
169781	*Genista holopetala*	1		1	S				
172945	*Gentiana ligustica*	1		1	P				
3506	*Geranium maderense*	1	1	1	P		MAC	PT	Madeira
3521	*Globularia ascanii*	1	1	1	P		MAC	ES	Canary Islands
3526	*Globularia sarcophylla*	1	1	1	P		MAC	ES	Canary Islands
175206	*Globularia stygia*	1	1	1	P		MED	GR	
3543	*Goodyera macrophylla*	1		1	O		MAC	PT	Madeira
9302	*Gymnigritella runei*	1		1	P		ALP	SE	
3569	*Helianthemum bystropogophyllum*	1	1	1	P		MAC	ES	Canary Islands
158305	*Helichrysum sibthorpii*			1	P		MED	GR	
3642	*Herniaria latifolia ssp. litardierei*	1	1	1	P		MED		
151254	*Hladnikia pastinacifolia*	1		1	S			SI	
152290	*Chaerophyllum azoricum*	1		1	O		MAC	PT	Azores
2654	*Chamaemeles coriacea*	1	1	1	S		MAC	PT	Madeira
9260	*Chionodoxa lochiae*	1	1	1	P		MED	CY	Troodos
9261	*Chionodoxa luciliae*			1	P				
3755	*Iberis arbuscula*	1	1	1	P		MED	GR	Aegean
186604	*Iris boissieri*			1	P		ATL	PT	Iberian
3791	*Isoplexis chalcantha*	1	1	1	O		MAC	ES	Canary Islands
3792	*Isoplexis isabelliana*	1		1	P		MAC	ES	Canary Islands
172706	*Jankaea heldreichii*			1	S		MED	GR	Mt Olymp
164917	*Jasione crispa ssp. serpentinica*	1		1	P		MED	PT	
164052	*Jonopsidium savianum*	1		1	S		MED		
156747	*Jurinea fontqueri*	1	1	1	P		MED	ES	
156751	*Lactuca watsoniana*	1	1	1	S		MAC	PT	Azores
157100	*Lamyropsis microcephala*	1	1	1	P		MED	IT	Sardinia
152142	*Laserpitium longiradium*	1	1	1	P		MED	ES	
156632	*Leontodon boryi*	1		1	P		MED	ES	
159135	*Leontodon microcephalus*	1		1	P		MED	ES	
185671	*Leucojum nicaeense*	1		1	S		MED		
159920	*Ligularia sibirica*	1		1	O				
4027	*Limonium dendroides*	1		1	O		MAC	ES	Canary Islands
4060	*Limonium sventenii*	1	1	1	O		MAC	ES	Canary Islands
183719	*Linaria tonzigii*	1		1	P		ALP	IT	Alps
189943	*Liparis loeselii*	1		1	O				
162004	*Lithodora nitida*	1	1	1	P		MED	ES	
186195	*Luzula arctica*	1		1	P				
176028	*Lythrum flexuosum*	1	1	1	S		MED	ES	
184965	*Mandragora officinarum*			1	O		MED		
174251	*Micromeria taygetea*	1	1	1	P		MED	GR	
167501	*Moehringia fontqueri*			1	P		MED	ES	
165493	*Moehringia tommasinii*	1		1	P				
165861	*Moehringia villosa*	1		1	P		ALP	SI	Alps
4433	*Monanthes wildpretii*	1		1	O		MAC	ES	Canary Islands
162668	*Murbeckiella sousae*			1	S		MED	PT	
4463	*Musschia wollastonii*	1	1	1	O		MAC	PT	Madeira
4478	*Myrica rivas-martinezii*	1	1	1	S		MAC	ES	Canary Islands
185527	*Narcissus asturiensis*	1		1	S				Iberian
185509	*Narcissus cyclamineus*	1		1	S				Iberian
185670	*Narcissus nevadensis*	1	1	1	P		MED	ES	
185677	*Narcissus pseudonarcissus ssp. nobilis*	1		1	S				Iberian
185760	*Narcissus triandrus*			1	S				
173600	*Nepeta dirphya*	1		1	S		MED	GR	
174797	*Nepeta sphaciotica*	1	1	1	P		MED	GR	Crete
183816	*Odontites granatensis*	1		1	P		MED	ES	

Species code ([a])	Species	Annex			Category ([c])	Habitat type	Endemic to		
		II	II* ([b])	IV			BGR ([d])	C ([e])	Other
198855	*Onopordum carduelinum*	1	1	1	P		MAC	ES	Canary Islands
9305	*Ophrys kotschyi*	1	1	1	S		MED	CY	
189706	*Ophrys lunulata*	1	1	1	S		MED		
4683	*Orchis scopulorum*			1	P		MAC	PT	Madeira
174322	*Origanum dictamnus*	1		1	S		MED	GR	Crete
188505	*Ornithogalum reverchonii*			1	S		MED		
175349	*Paeonia cambessedesii*	1		1	S		MED	ES	Balearic
175599	*Papaver laestadianum*	1		1	P		ALP		
195549	*Papaver radicatum ssp. hyperboreum*	1		1	P		ALP		
4801	*Pericallis hadrosoma*	1	1	1	P		MAC	ES	Canary Islands
165499	*Petrocoptis grandiflora*	1		1	S			ES	
195082	*Petrocoptis montsicciana*	1		1	S			ES	
195079	*Petrocoptis pseudoviscosa*	1		1	S			ES	
9201	*Phlomis brevibracteata*	1		1	S		MED	CY	
9202	*Phlomis cypria*	1		1	O		MED	CY	
164848	*Physoplexis comosa*			1	S		ALP		Alps
9218	*Pinguicula crystallina*	1	1	1	S		MED		
176081	*Pinguicula nevadensis*	1		1	P		MED	ES	
189799	*Platanthera obtusata ssp. oligantha*	1		1	P				
193603	*Poa granitica ssp. disparilis*	1		1	P		ALP	RO	Carpathians
192439	*Poa laxa*			1	P				
192438	*Poa riphaea*	1	1	1	P		CON	CZ	Hruby Jesenik
180036	*Potentilla delphinensis*	1		1	P		ALP	FR	
179034	*Primula apennina*	1	1	1	P		CON	IT	Appenines
178867	*Primula carniolica*	1		1	S			SI	Dinaric
179089	*Primula glaucescens*			1	P		ALP	IT	Alps
179081	*Primula scandinavica*	1		1	P				Scandinavia
179028	*Primula spectabilis*			1	P		ALP	IT	Alps
177071	*Pulsatilla grandis*	1		1	O				
176925	*Pulsatilla slavica*	1	1	1	P		ALP		Carpathians
196481	*Pulsatilla subslavica*	1	1	1	S			SK	Carpathians
172700	*Ramonda serbica*			1	S				Balkan
9111	*Ranunculus kykkoensis*	1		1	P		MED	CY	Troodos
176670	*Ranunculus weyleri*	1	1	1	S		MED	ES	Mallorca
169518	*Rhododendron luteum*	1		1	S				
173131	*Ribes sardoum*	1	1	1	P		MED	IT	Sardinia
5459	*Sambucus palmensis*	1	1	1	S		MAC	ES	Canary Islands
151605	*Sanicula azorica*	1		1	O		MAC	PT	Azores
161632	*Santolina elegans*			1	P		MED	ES	
5482	*Santolina semidentata*	1		1	S				Iberian
181427	*Saxifraga florulenta*	1		1	P		ALP		Alps
181463	*Saxifraga hirculus*	1		1	S				
5532	*Saxifraga portosanctana*			1	P		MAC	PT	Madeira
181557	*Saxifraga presolanensis*			1	P		ALP	IT	Alps
181615	*Saxifraga tombeanensis*	1		1	S		ALP	IT	Alps
181620	*Saxifraga valdensis*			1	P		ALP		
181622	*Saxifraga vayredana*			1	S		MED	ES	
169222	*Scabiosa nitens*	1		1	O		MAC	PT	Azores
9273	*Scilla morrisii*	1	1	1	S		MED	CY	Troodos
5667	*Senecio caespitosus*			1	P		MED	PT	
159710	*Senecio elodes*	1	1	1	P		MED	ES	
160018	*Senecio nevadensis*	1		1	P		MED	ES	
151041	*Seseli intricatum*	1	1	1	P		MED	ES	
9204	*Sideritis cypria*	1		1	S		MED	CY	
5732	*Sideritis cystosiphon*	1	1	1	O		MAC	ES	Canary Islands
5733	*Sideritis discolor*	1	1	1	S		MAC	ES	Canary Islands
5735	*Sideritis infernalis*	1		1	S		MAC	ES	Canary Islands

Species code ([a])	Species	Annex			Category ([c])	Habitat type	Endemic to		
		II	II* ([b])	IV			BGR ([d])	C ([e])	Other
174816	*Sideritis javalambrensis*	1		1	P		MED	ES	
165612	*Silene furcata ssp. angustiflora*	1		1	S				
195205	*Silene mariana*	1		1	O		MED	ES	
167606	*Silene orphanidis*	1	1	1	P		MED	GR	Mt Athos
162711	*Sisymbrium supinum*	1		1	S				
5808	*Solanum lidii*	1	1	1	O		MAC	ES	Canary Islands
162277	*Solenanthus albanicus*	1		1	P		MED		
5822	*Sorbus maderensis*	1		1	S		MAC	PT	Madeira
190075	*Spiranthes aestivalis*			1	S				
160924	*Stemmacantha cynaroides*	1		1	P		MAC	ES	Canary Islands
193469	*Stipa austroitalica*	1	1	1	S		MED	IT	
192762	*Stipa styriaca*	1	1	1	P		ALP	AT	
5962	*Tanacetum ptarmiciflorum*	1	1	1	P		MAC	ES	Canary Islands
196440	*Tephroseris longifolia ssp. moravica*	1		1	S				Carpathians
184626	*Thymelaea broterana*			1	S				Iberian
184258	*Tozzia carpathica*	1		1	P				
170699	*Trifolium saxatile*	1		1	P		ALP		Alps
193489	*Trisetum subalpestre*	1		1	P				
183320	*Veronica micrantha*	1		1	S		ATL		Iberian
6235	*Veronica oetaea*	1	1	1	P		MED	GR	
185408	*Viola athois*			1	P		MED	GR	
185392	*Viola cazorlensis*			1	P		MED	ES	
185374	*Viola delphinantha*	1		1	P				Balkan
185320	*Viola jaubertiana*	1		1	S		MED	ES	Mallorca
185238	*Viola rupestris ssp. relicta*	1		1	P				
160691	*Wagenitzia lancifolia*			1	P		MED	GR	Crete
185165	*Zelkova abelicea*	1		1	P		MED	GR	Crete

Note: ([a]) Code of species in EUNIS species database.
([b]) Taxa listed in the Habitat Directive Annex II as priority species.
([c]) 'P' refers to exclusively mountain species; 'S' refers to mainly mountain species; 'O' refers to facultative mountain species.
([d]) Biogeographical regions: ALP — Alpine; ATL — Atlantic; CON — Continental; MAC — Macaronesian; MED — Mediterranean.
([e]) Countries: AT — Austria; CY — Cyprus; CZ — Czech Republic; ES — Spain; FR — France; GR — Greece; IT — Italy; PT — Portugal; RO — Romania; SE — Sweden; SK — Slovakia.

Appendix 2 Mountain habitat types in the Habitats Directive

Code ([a])	Name	Category ([b])
1 Coastal and halophytic habitats		
11	**Open sea and tidal areas**	
1110	Sandbanks which are slightly covered by sea water all the time	N
1120	* *Posidonia* beds (*Posidonion oceanicae*)	N
1130	Estuaries	N
1140	Mudflats and sandflats not covered by seawater at low tide	N
1150	* Coastal lagoons	N
1160	Large shallow inlets and bays	N
1170	Reefs	N
1180	Submarine structures made by leaking gases	N
12	**Sea cliffs and shingle or stony beaches**	
1210	Annual vegetation of drift lines	N
1220	Perennial vegetation of stony banks	N
1230	Vegetated sea cliffs of the Atlantic and Baltic Coasts	N
1240	Vegetated sea cliffs of the Mediterranean coasts with endemic *Limonium* spp.	N
1250	Vegetated sea cliffs with endemic flora of the Macaronesian coasts	N
13	**Atlantic and continental salt marshes and salt meadows**	
1310	*Salicornia* and other annuals colonising mud and sand	N
1320	*Spartina* swards (*Spartinion maritimae*)	N
1330	Atlantic salt meadows (*Glauco-Puccinellietalia maritimae*)	N
1340	* Inland salt meadows	N
14	**Mediterranean and thermo-Atlantic salt marshes and salt meadows**	
1410	Mediterranean salt meadows (*Juncetalia maritimi*)	N
1420	Mediterranean and thermo-Atlantic halophilous scrubs (*Sarcocornetea fruticosi*)	N
1430	Halo-nitrophilous scrubs (*Pegano-Salsoletea*)	N
15	**Salt and gypsum inland steppes**	
1510	* Mediterranean salt steppes (*Limonietalia*)	N
1520	* Iberian gypsum vegetation (*Gypsophiletalia*)	N
1530	* Pannonic salt steppes and salt marshes	N
16	**Boreal Baltic archipelago, coastal and landupheaval areas**	
1610	Baltic esker islands with sandy, rocky and shingle beach vegetation and sublittoral vegetation	N
1620	Boreal Baltic islets and small islands	N
1630	* Boreal Baltic coastal meadows	N
1640	Boreal Baltic sandy beaches with perennial vegetation	N
1650	Boreal Baltic narrow inlets	N
2 Coastal sand dunes and inland dunes		
21	**Sea dunes of the Atlantic, North Sea and Baltic coasts**	
2110	Embryonic shifting dunes	N
2120	Shifting dunes along the shoreline with *Ammophila arenaria* ('white dunes')	N
2130	* Fixed coastal dunes with herbaceous vegetation (“grey dunes')	N
2140	* Decalcified fixed dunes with *Empetrum nigrum*	N
2150	* Atlantic decalcified fixed dunes (*Calluno-Ulicetea*)	N
2160	Dunes with *Hippophaë rhamnoides*	N
2170	Dunes with *Salix repens* ssp. *argentea* (*Salicion arenariae*)	N
2180	Wooded dunes of the Atlantic, Continental and Boreal region	N
2190	Humid dune slacks	N
21A0	Machairs (* in Ireland)	N
22	**Sea dunes of the Mediterranean coast**	
2210	*Crucianellion maritimae* fixed beach dunes	N
2220	Dunes with *Euphorbia terracina*	N
2230	*Malcolmietalia* dune grasslands	N

Code ([a])	Name	Category ([b])
2240	*Brachypodietalia* dune grasslands with annuals	N
2250	* Coastal dunes with *Juniperus* spp.	N
2260	*Cisto-Lavenduletalia* dune sclerophyllous scrubs	N
2270	* Wooded dunes with *Pinus pinea* and/or *Pinus pinaster*	N
23	**Inland dunes, old and decalcified**	
2310	Dry sand heaths with *Calluna* and *Genista*	N
2320	Dry sand heaths with *Calluna* and *Empetrum nigrum*	N
2330	Inland dunes with open *Corynephorus* and *Agrostis* grasslands	N
2340	* Pannonic inland dunes	N
3 Freshwater habitats		
31	**Standing water**	
3110	Oligotrophic waters containing very few minerals of sandy plains (*Littorelletalia uniflorae*)	F
3120	Oligotrophic waters containing very few minerals generally on sandy soils of the West Mediterranean, with *Isoetes* spp.	N
3130	Oligotrophic to mesotrophic standing waters with vegetation of the *Littorelletea uniflorae* and/or of the *Isoëto-Nanojuncetea*	F
3140	Hard oligo-mesotrophic waters with benthic vegetation of *Chara* spp.	F
3150	Natural eutrophic lakes with *Magnopotamion* or *Hydrocharition* — type vegetation	F
3160	Natural dystrophic lakes and ponds	F
3170	* Mediterranean temporary ponds	N
3180	* Turloughs	N
3190	Lakes of gypsum karst	N
31A0	* Transylvanian hot-spring lotus beds	N
32	**Running water**	
3210	Fennoscandian natural rivers	F
3220	Alpine rivers and the herbaceous vegetation along their banks	M
3230	Alpine rivers and their ligneous vegetation with *Myricaria germanica*	M
3240	Alpine rivers and their ligneous vegetation with *Salix elaeagnos*	M
3250	Constantly flowing Mediterranean rivers with *Glaucium flavum*	N
3260	Water courses of plain to montane levels with the *Ranunculion fluitantis* and *Callitricho-Batrachion* vegetation	F
3270	Rivers with muddy banks with *Chenopodion rubri* p.p. and *Bidention* p.p. vegetation	F
3280	Constantly flowing Mediterranean rivers with *Paspalo-Agrostidion* species and hanging curtains of *Salix* and *Populus alba*	N
3290	Intermittently flowing Mediterranean rivers of the *Paspalo-Agrostidion*	N
4 Temperate heath and scrub		
4010	Northern Atlantic wet heaths with *Erica tetralix*	F
4020	* Temperate Atlantic wet heaths with *Erica ciliaris* and *Erica tetralix*	F
4030	European dry heaths	F
4040	* Dry Atlantic coastal heaths with *Erica vagans*	N
4050	* Endemic macaronesian heaths	F
4060	Alpine and Boreal heaths	M
4070	* Bushes with *Pinus mugo* and *Rhododendron hirsutum* (*Mugo-Rhododendretum hirsuti*)	M
4080	Sub-Arctic *Salix* spp. Scrub	M
4090	Endemic oro-Mediterranean heaths with gorse	M
40A0	* Subcontinental peri-Pannonic scrub	N
40B0	Rhodope *Potentilla fruticosa* thickets	M
40C0	* Ponto-Sarmatic deciduous thickets	N
5 Sclerophyllous scrub (matorral)		
51	**Sub-Mediterranean and temperate scrub**	
5110	Stable xerothermophilous formations with *Buxus sempervirens* on rock slopes (*Berberidion* p.p.)	F
5120	Mountain *Cytisus purgans* formations	M
5130	*Juniperus communis* formations on heaths or calcareous grasslands	F
5140	* *Cistus palhinhae* formations on maritime wet heaths	N
52	**Mediterranean arborescent matorral**	
5210	Arborescent matorral with *Juniperus* spp.	F
5220	* Arborescent matorral with *Zyziphus*	N
5230	* Arborescent matorral with *Laurus nobilis*	F
53	**Thermo-Mediterranean and pre-steppe brush**	
5310	*Laurus nobilis* thickets	F

Code ([a])	Name	Category ([b])
5320	Low formations of Euphorbia close to cliffs	N
5330	Thermo-Mediterranean and pre-desert scrub	N
54	**Phrygana**	
5410	West Mediterranean clifftop phryganas (*Astragalo-Plantaginetum subulatae*)	N
5420	Sarcopoterium spinosum phryganas	N
5430	Endemic phryganas of the *Euphorbio-Verbascion*	F
6 Natural and semi-natural grassland formations		
61	**Natural grasslands**	
6110	* Rupicolous calcareous or basophilic grasslands of the *Alysso-Sedion albi*	F
6120	* Xeric sand calcareous grasslands	N
6130	Calaminarian grasslands of the *Violetalia calaminariae*	F
6140	Siliceous Pyrenean *Festuca eskia* grasslands	M
6150	Siliceous alpine and boreal grasslands	M
6160	Oro-Iberian *Festuca indigesta* grasslands	M
6170	Alpine and subalpine calcareous grasslands	M
6180	Macaronesian mesophile grasslands	M
6190	Rupicolous pannonic grasslands (*Stipo-Festucetalia pallentis*)	F
62	**Semi-natural dry grasslands and scrubland facies**	
6210	Semi-natural dry grasslands and scrubland facies on calcareous substrates (*Festuco-Brometalia*) (* important orchid sites)	F
6220	* Pseudo-steppe with grasses and annuals of the *Thero-Brachypodietea*	F
6230	* Species-rich *Nardus* grasslands, on silicious substrates in mountain areas (and submountain areas in Continental Europe)	F
6240	* Sub-Pannonic steppic grasslands	N
6250	* Pannonic loess steppic grasslands	N
6260	* Pannonic sand steppes	N
6270	* Fennoscandian lowland species-rich dry to mesic grasslands	N
6280	* Nordic alvar and precambrian calcareous flatrocks	N
62A0	Eastern sub-Mediterranean dry grasslands (*Scorzoneratalia villosae*)	N
62B0	* Serpentinophilous grassland of Cyprus	F
62C0	* Ponto-Sarmatic steppes	N
62D0	Oro-Moesian acidophilous grasslands	M
63	**Sclerophillous grazed forests (dehesas)**	
6310	Dehesas with evergreen *Quercus* spp.	N
64	**Semi-natural tall-herb humid meadows**	
6410	*Molinia* meadows on calcareous, peaty or clayey-silt-laden soils (*Molinion caeruleae*)	F
6420	Mediterranean tall humid grasslands of the *Molinio-Holoschoenion*	F
6430	Hydrophilous tall herb fringe communities of plains and of the montane to alpine levels	F
6440	Alluvial meadows of river valleys of the *Cnidion dubii*	N
6450	Northern boreal alluvial meadows	F
6460	Peat grasslands of Troodos	M
65	**Mesophile grasslands**	
6510	Lowland hay meadows (*Alopecurus pratensis, Sanguisorba officinalis*)	N
6520	Mountain hay meadows	M
6530	* Fennoscandian wooded meadows	N
7 Raised bogs and mires and fens		
71	**Sphagnum acid bogs**	
7110	* Active raised bogs	F
7120	Degraded raised bogs still capable of natural regeneration	F
7130	Blanket bogs (* if active bog)	F
7140	Transition mires and quaking bogs	F
7150	Depressions on peat substrates of the *Rhynchosporion*	F
7160	Fennoscandian mineral-rich springs and springfens	F
72	**Calcareous fens**	
7210	* Calcareous fens with *Cladium mariscus* and species of the *Caricion davallianae*	F
7220	* Petrifying springs with tufa formation (*Cratoneurion*)	F
7230	Alkaline fens	F
7240	* Alpine pioneer formations of the *Caricion bicoloris-atrofuscae*	M
73	**Boreal mires**	
7310	* Aapa mires	F
7320	* Palsa mires	M

Code ([a])	Name	Category ([b])
8 Rocky habitats and caves		
81	**Scree**	
8110	Siliceous scree of the montane to snow levels (*Androsacetalia alpinae and Galeopsietalia ladani*)	M
8120	Calcareous and calcshist screes of the montane to alpine levels (*Thlaspietea rotundifolii*)	M
8130	Western Mediterranean and thermophilous scree	F
8140	Eastern Mediterranean screes	M
8150	Medio-European upland siliceous screes	F
8160	* Medio-European calcareous scree of hill and montane levels	F
82	**Rocky slopes with chasmophytic vegetation**	
8210	Calcareous rocky slopes with chasmophytic vegetation	F
8220	Siliceous rocky slopes with chasmophytic vegetation	F
8230	Siliceous rock with pioneer vegetation of the *Sedo-Scleranthion* or of the *Sedo albi-Veronicion dillenii*	F
8240	* Limestone pavements	F
83	**Other rocky habitats**	
8310	Caves not open to the public	F
8320	Fields of lava and natural excavations	F
8330	Submerged or partially submerged sea caves	N
8340	Permanent glaciers	M
9 Forests		
90	**Forests of Boreal Europe**	
9010	* Western Taïga	F
9020	* Fennoscandian hemiboreal natural old broad-leaved deciduous forests (*Quercus, Tilia, Acer, Fraxinus or Ulmus*) rich in epiphytes	F
9030	* Natural forests of primary succession stages of landupheaval coast	N
9040	Nordic subalpine/subarctic forests with *Betula pubescens* ssp. *czerepanovii*	M
9050	Fennoscandian herb-rich forests with *Picea abies*	F
9060	Coniferous forests on, or connected to, glaciofluvial eskers	F
9070	Fennoscandian wooded pastures	F
9080	* Fennoscandian deciduous swamp woods	F
91	**Forests of Temperate Europe**	
9110	*Luzulo-Fagetum* beech forests	F
9120	Atlantic acidophilous beech forests with *Ilex* and sometimes also *Taxus* in the shrublayer (*Quercion robori-petraeae or Ilici-Fagenion*)	F
9130	*Asperulo-Fagetum* beech forests	F
9140	Medio-European subalpine beech woods with *Acer* and *Rumex arifolius*	M
9150	Medio-European limestone beech forests of the *Cephalanthero-Fagion*	F
9160	Sub-Atlantic and medio-European oak or oak-hornbeam forests of the *Carpinion betuli*	F
9170	*Galio-Carpinetum* oak-hornbeam forests	F
9180	* *Tilio-Acerion* forests of slopes, screes and ravines	F
9190	Old acidophilous oak woods with *Quercus robur* on sandy plains	N
91A0	Old sessile oak woods with *Ilex* and *Blechnum* in the British Isles	F
91B0	Thermophilous *Fraxinus angustifolia* woods	F
91C0	* Caledonian forest	M
91D0	* Bog woodland	F
91E0	* Alluvial forests with *Alnus glutinosa* and *Fraxinus excelsior* (*Alno-Padion, Alnion incanae, Salicion albae*)	F
91F0	Riparian mixed forests of *Quercus robur, Ulmus laevis* and *Ulmus minor*, *Fraxinus excelsior* or *Fraxinus angustifolia*, along the great rivers (*Ulmenion minoris*)	F
91G0	* Pannonic woods with *Quercus petraea* and *Carpinus betulus*	N
91H0	* Pannonian woods with *Quercus pubescens*	N
91I0	* Euro-Siberian steppic woods with *Quercus* spp.	N
91J0	* *Taxus baccata* woods of the British Isles	N
91K0	Illyrian *Fagus sylvatica* forests (*Aremonio-Fagion*)	F
91L0	Illyrian oak-hornbeam forests (*Erythronio-Carpinion*)	F
91M0	Pannonian-Balkanic turkey oak –sessile oak forests	N
91N0	* Pannonic inland sand dune thicket (*Junipero-Populetum albae*)	N
91P0	Holy Cross fir forest (*Abietetum polonicum*)	F
91Q0	Western Carpathian calcicolous *Pinus sylvestris* forests	M
91R0	Dinaric dolomite Scots pine forests (*Genisto januensis-Pinetum*)	F
91S0	* Western Pontic beech forests	F

Code ([a])	Name	Category ([b])
91T0	Central European lichen Scots pine forests	N
91U0	Sarmatic steppe pine forest	N
91V0	Dacian Beech forests (*Symphyto-Fagion*)	F
91W0	Moesian beech forests	M
91X0	* Dobrogean beech forests	N
91Y0	Dacian oak & hornbeam forests	N
91Z0	Moesian silver lime woods	N
91AA	* Eastern white oak woods	F
91BA	Moesian silver fir forests	M
91CA	Rhodopide and Balkan Range Scots pine forests	F
92	**Mediterranean deciduous forests**	
9210	* Apeninne beech forests with *Taxus* and *Ilex*	F
9220	* Apennine beech forests with *Abies alba* and beech forests with *Abies nebrodensis*	F
9230	Galicio-Portuguese oak woods with *Quercus robur* and *Quercus pyrenaica*	F
9240	*Quercus faginea* and *Quercus canariensis* Iberian woods	F
9250	*Quercus trojana* woods	F
9260	*Castanea sativa* woods	F
9270	Hellenic beech forests with *Abies borisii-regis*	F
9280	*Quercus frainetto* woods	F
9290	*Cupressus* forests (*Acero-Cupression*)	M
92A0	*Salix alba* and *Populus alba* galleries	N
92B0	Riparian formations on intermittent Mediterranean water courses with *Rhododendron ponticum, Salix* and others	N
92C0	*Platanus orientalis* and *Liquidambar orientalis* woods (*Platanion orientalis*)	M
92D0	Southern riparian galleries and thickets (*Nerio-Tamaricetea* and *Securinegion tinctoriae*)	M
93	**Mediterranean sclerophyllous forests**	
9310	Aegean *Quercus brachyphylla* woods	N
9320	*Olea* and *Ceratonia* forests	N
9330	*Quercus suber* forests	F
9340	*Quercus ilex* and *Quercus rotundifolia* forests	F
9350	*Quercus macrolepis* forests	N
9360	* Macaronesian laurel forests (*Laurus, Ocotea*)	F
9370	* Palm groves of *Phoenix*	N
9380	Forests of *Ilex aquifolium*	F
9390	* Scrub and low forest vegetation with *Quercus alnifolia*	F
93A0	Woodlands with *Quercus infectoria* (*Anagyro foetidae-Quercetum infectoriae*)	F
94	**Temperate mountainous coniferous forests**	
9410	Acidophilous *Picea* forests of the montane to alpine levels (*Vaccinio-Piceetea*)	M
9420	Alpine *Larix decidua* and/or *Pinus cembra* forests	M
9430	Subalpine and montane *Pinus uncinata* forests (* if on gypsum or limestone)	M
95	**Mediterranean and Macaronesian mountainous coniferous forests**	
9510	* Southern Apennine *Abies alba* forests	M
9520	*Abies pinsapo* forests	M
9530	* (Sub-) Mediterranean pine forests with endemic black pines	M
9540	Mediterranean pine forests with endemic Mesogean pines	F
9550	Canarian endemic pine forests	M
9560	* Endemic forests with *Juniperus* spp.	F
9570	* *Tetraclinis articulata* forests	F
9580	* Mediterranean *Taxus baccata* woods	M
9590	* *Cedrus brevifolia* forests (*Cedrosetum brevifoliae*)	M
95A0	High oro-Mediterranean pine forests	M

Note: * Indicates a priority habitat.
([a]) Habitat type code as used by the Annex I of the Habitats Directive.
([b]) 'M' refers to mountain habitats (habitats exclusively or almost exclusively distributed in mountains); 'F' refers to partially mountain habitats (habitat types distributed both inside and outside mountains); 'N' refers to non-mountain habitats (habitat types distributed exclusively or almost exclusively outside mountains.

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